PRODUCTION ENGINEERING

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PREFACE

The criticism is often made that too much of the teaching in engineering schools is of the "pigeon-hole" variety; that individual subjects are presented to the students without concerted attempt to make them a coherent whole. The student is expected to recognize their relative position in the general scheme of education and their inter-dependence upon each other when applied to the solution of any specific problem. A few students may achieve this perspective and get a reasonably integrated education, but the majority may not become fully aware of these relationships until after some years of practical experience, when most of the detail of specialized courses has been relegated to the dim recesses of memory.

In the field of production engineering we have all the technical problems related to the product, the manufacturing processes, and the plant. Texts and educational courses which are available cover basic studies such as mathematics, physics, chemistry, theoretical and applied mechanics, and many specialized subjects such as machine design, mechanics of materials, generation and transmission of power, lubrication, mechanical processes, cutting of metals, tool design, standardization, inspection and testing, materials handling. These texts present many of the elements of production engineering.

This volume has been written expressly to point out the relationship of all the above-mentioned details and to emphasize the importance of active cooperation at all times and in all directions for the most effective performance of the multitudinous activities involved. It may be considered as an assembly drawing of the subject. No attempt has been made to treat in detail any part of this work of production engineering except where the existing texts appear to be inadequate or non-existent.

The work of production engineering is here presented as the coordinated efforts of many individuals, each of whom has a specific task to accomplish. These tasks involve not only the obligation of carrying through the work in conformity with the plans of some who have completed the earlier stages, but also the responsibility of reporting back to those collaborators the results of their joint efforts, together with

suggestions for present or future improvements. In other words, information and suggestions or constructive criticism must flow constantly in both directions.

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Particular credit must be given to my wife, Nina W. Morgan Buckingham, who "Englished" my original manuscript and has given to this text whatever elements of style it may possess.

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CHAPTER I

INTRODUCTION

The problem of production engineering has three major phases. The first is to prepare for and to start the production of a new product or to make a major change in the design of an existing product. The second is the orderly and effective operation of the plant in the continued production of the product. This involves minor changes in design, generally made to facilitate manufacture, together with changes and improvements in manufacturing processes and the introduction of new manufacturing processes. The problems created by changes in both increased and decreased production are met here. The third includes the continuing and supporting activities that gather information and put it into effective form for its direct application to the two preceding phases.

Modern production today involves an almost infinite number of petty details which must be taken care of by the cooperative effort of many persons. The orderly handling of much detail necessitates setting up a definite routine for most of it. It should be remembered, however, that such routine is established to handle the ordinary, or usual, conditions; unusual cases will always require special consideration. In other words, routine is a tool or method devised to assist us in the control of a mass of detail; but, for more effective handling another method may be employed for any particular detail. Routine should be maintained, however, unless the one suggesting the change can justify the departure from established routine.

The essence of modern production is the breaking down of the productive effort into simple and elementary tasks, so that less skill, or rather a lesser range of skills is required of the machine operator. To attain this end, as much as possible of the skill and technique formerly brought to the work by the craftsman must be supplied by the equipment. The further this substitution is carried, the greater are the skill and technique which must be brought to the problem by the production engineer, the machine maker, the tool maker and the other craftsmen who design, build, and set up this productive equipment.

The many details of production engineering likewise tend to be divided into more and more specialties, so that when a task of any magnitude is to be done, a large group of specialists must be organized

to handle it. When time is the important consideration, as is usually the case in preparation, complete cooperation must exist between them, unless chaos and seemingly endless delays are to result. The essentials of effective cooperation are four. First, all persons in authority must have a full realization of the objectives, and the same understanding of them. Second, each one cooperating must have some understanding of the character, responsibilities, difficulties, and limitations of the others' tasks. Third, each responsible person must be a master of his own specialized task. Fourth, and not least by any means, each responsible person must have a definite understanding of his own responsibility and authority.

It seems axiomatic that responsibility and authority are indivisible. No person or organization can justly be held responsible for conditions over which they have no control. On the other hand, any delegation of responsibility carries with it only that authority necessary to carry out the specific task assigned. The form of an organization and the resulting delegation of responsibility is often determined by the aptitude and experience of the individuals forming the group. Of course, certain factors of production engineering logically involve certain responsibilities, and, if responsibilities are to be effectively met, should automatically carry with them certain controls, or authority, regardless of the detailed form of organization. One of the primary purposes of this text is to point out the fundamental lines of responsibility and authority involved in this maze of production engineering activities. No claim is made that this analysis is complete or infallible. Varying combinations of tasks may be assigned to departments and their sections to achieve equivalent results. The attempt will be made, however, to develop a logical analysis of cause and effect.

Let us start the consideration of the subject of production engineering by listing some of the more important factors of the problem, beginning with the initial preparation for production.

Preparation for Production

Functional Design

The first essential of production engineering is to have a product worth making. The initial design of this product will be called the functional design. In its development, the major objective is to make a product that will perform some function or render a definite service. Some thought may be given here to possible methods of manufacture, yet the greatest emphasis is on its ultimate use in the hands of the consumer.

This functional design may be developed in an existing plant, or it

may be brought to it from some outside source. It is the responsibility of the management, assisted, of course, by information and advice, wherever they may be found in other parts of the organization, to decide whether or not to accept this new product for production. Certain definite objectives and requirements should be set up at the start: (a) performance requirements of the product, (b) cost of manufacture, (c) quantity, or rate of production, depending upon the size of the potential market, (d) cost of preparation for production, (e) elapsed time required to start production.

Production Design

The production design consists primarily of a critical survey of the details of the functional design. Details should be changed whenever the change will expedite manufacture with the equipment that is, or may be, available. The survey includes the setting of tolerances or of permissible variations in size of the numerous elements of the component parts; the selection of suitable materials; the simplification of the design wherever possible; and the use of as many existing standard parts and elements as possible. Indispensable as is the functional design, it is the effectiveness of the production design that largely determines the commercial success or failure of the new product.

It is, or should be, the responsibility of the production engineering staff—possibly a production design group—to develop this production design. Whatever is left undone on the production design must be completed or corrected after production is under way. Although the major part of the production design should be completed before production is started, it is never finished while production continues. Such changes to facilitate manufacture should never require the approval of the functional designer. The latter should have the veto power only over changes that would impair the performance of the product. Objections may be raised over any proposed change, and the resulting arguments, more often than not, are differences of opinion rather than statements of fact. If questions arise, it is generally possible to make simple experiments, or in extreme cases, to build a model with the proposed changes incorporated, to prove or disprove these differences of opinion.

Estimating

Preliminary estimates are needed to guide the management in its decision regarding the acceptance or rejection of a new product, and also to set up the original objectives and requirements. A more detailed estimate is usually required after the new product has been accepted for production. Such estimates, properly made, serve as a valu-

able guide to the work of preparation for production which follows, and they also enable an increasingly larger group to work consistently towards the common objective.

All estimating is the responsibility of the preparation group of the production engineering staff. Records and statistics of past performances are an invaluable aid to this work. In general, these estimates give a remarkably accurate forecast of the time and money required for a given project. Too often, however, records of elapsed time, from starting to completion of the preparation, are not kept, and predictions of the actual date when production will be under way, and proceeding smoothly, are much too optimistic.

Operation Layouts and Schedules

The operation layouts are developed from the estimates and specify the various machining operations, their sequence, machines and tools and gages required, and the amount of equipment needed to meet a specified rate of production. This work should also include a schedule, which should take into account the elapsed time needed to design, build, and set up the special equipment. The schedule establishes the order, in point of time, in which each task is started and finished so that the specified date for the beginning of production may be met. At times, notes and sketches of some of the unusual features of a tool or fixture should be included to assist the tool designer in his work. Usually the locating and holding points on the part should be specified.

Operation layouts may also include the making of factory layouts which show the location of the equipment in the plant. The preparation group of the production engineering staff is responsible for the completion of these operation layouts and should retain this responsibility until the equipment is actually producing the parts satisfactorily.

Tool Design

The drafting of the jigs, fixtures, tools, gages, and any other special equipment may be done in the tool design department. This work should be supervised or checked by the process engineer who made up the specific operation layout. Frequently these tool designers are specialists on tools for certain specific processes. They are responsible for the accuracy and adequacy of their drawings, but the process engineer in charge of a specific component part of the product is responsible for the proper selection of holding points and the coherence of the series of tools needed to produce that part.

An increasing number of plants is reducing tool-making and tool-designing facilities to the minimum needed for maintenance of cur-

rent production, so that both the tool designing and the tool making are done by outside companies. In addition, when new machines are required, the machine tool builder is often required to furnish the machine completely tooled for a specific operation. Here the responsibility of the tool design is delegated to an outside organization. The process engineer in charge of the specific component should then make sure that the correct and necessary information is given to that outside source, since none of his responsibility has been delegated to others.

Requisitions and Schedules for Equipment

It is the responsibility of the process engineer in charge of a given component to see that orders are issued for the design and the construction of the necessary special equipment, and that schedules showing the sequence and dates when each job should be started and finished are prepared. The clerical work involved may be done in a centralized or general clerical section, but it is his responsibility to see that the section receives the necessary information, and to make sure that the clerical work has been actually done. These requisitions are based on the operation layouts. Questions of priority between the several process engineers should be settled by the chief of the section; similar questions between the preparation group and the maintenance or production group should be settled by the general management. This is a problem of interference with routine production by the preparation for a new product, and it is also a question of general policy.

Checking of Tools and Tool-Made Samples

The inspection of new tools, often accomplished by the measurement of work actually produced by the tool, may be done by mechanics and tool inspectors who are responsible only for the accuracy of measurements. The process engineer is responsible for the adequacy of the results. It may be that the same inspectors are used for the checking of tools for new designs and for the routine inspection of replacement tools for the existing production. This, however, does not modify their responsibility.

Initial Production of New Product

The setting-up, adjustment, and operation of the equipment for a new product may be done by the regular production force, but the process engineer who has planned this work should continue to be responsible for its performance until it has definitely proved itself in practice. This means that he must give this part of the work sufficient supervision so that all necessary information is in the hands or minds

of the proper persons. Definite cooperation is needed here between the planner and the producer. Similar cooperation is usually needed at the very start of the planning.

Checking the Performance of the Initial Assembled Product

The acid test of the adequacy and completeness of the production design, choice of materials, and all the other preparation activities comes when the first of the tool-made parts are assembled and tested for performance. If the product assembles without difficulty, the parts interchange readily, and the assembled product meets all performance specifications satisfactorily, it is conclusive proof that the problem has been solved. On the other hand, if difficulty is met in any of these places, it is equally conclusive proof of incomplete planning, or mistakes, and the preparation group is responsible for these conditions, and must take prompt steps to complete or to correct its work.

Investigation and Correction of Initial Troubles

Experience in the problem of starting production on a new product indicates that some difficulties exist always at the initial stages of production. Some of them are due to ignorance or lack of the necessary special training on the part of the operators; some may be caused by misunderstandings, and lack of full cooperation between the planning group and the production group; some are present because of the incompleteness of the planning; but too often most of them are caused by definite mistakes or ignorance on the part of the planning group. The majority of changes on the part drawings during the first days of production—most of them made to facilitate manufacture—are evidence of an incorrect or an incomplete production design. Unfortunately, many of these escape attention until some of all parts have been made and the first assemblies are on test. Regardless of the cause of the trouble, however, the planning group should be responsible for investigating each of them and for correcting the trouble at its source. Close cooperation with the production group will prove invaluable here also.

The foregoing is an attempt at a brief outline of the more important activities involved in the preparation for production. Whether a plant is large or small, these problems will be present. In a small plant, one person or a small group may be responsible for their solution. With a large plant, a considerable organization may be required and the various problems may be divided and sub-divided among several sections.

Let us now consider the more important problems of production

after what is often a "nightmare" of starting difficulties is well behind us.

Production Operation and Control

Production Schedules and Follow-Up

The production requirements are established by the general management, but these are usually in terms of assembled products. The requirements must be broken down, not only into the individual component parts, but also into the individual operations on each part. Schedules must be prepared for the production which will take into consideration all the other work in the plant. All schedules must be followed up, and hold-ups and conflicts with other schedules reported if predetermined delivery schedules are to be met. Among the component parts will often be found some which are common to several of the products. These are known as stock, or standard parts. They may be made in lots without reference to the specific product orders. It is necessary, in such cases, to determine the economical size of lot to manufacture and the minimum quantity of this stock part to have on hand before starting the manufacture of a new lot. The planning and control of the details are responsibilities of the production engineer. The clerical work involved may be done in some centralized clerical department, but it is the responsibility of the production engineer to see that it is done correctly and on time.

Material Procurement and Schedules

The material required to make the product is usually ordered by the purchasing agent, but it is the responsibility of the production engineer to see that the purchasing agent has the necessary information to buy the materials required and to keep him informed of the amount needed and when it must be on hand. The amount of any specific material ordered may be based directly upon the production orders in hand, or it may be ordered for stock, as is done with standard parts, when there is any economic advantage in so doing, or if it is a critical material that may be difficult to get at short notice. Such conditions may change with time, and the whole material procurement problem may involve a question of policy which needs the approval of the general management. Here the detailed requirements are furnished by the production engineer, the procurement problem is stated by the purchasing agent, and the policy is established by the general management.

Training of Labor

The training of operators for specific duties is generally the responsibility of the department foremen. The actual hiring may be through

a centralized employment department. Such training might well be a part of the process engineer's responsibility. The selection of persons for specific duties should be under the control of the department foreman. The majority of productive operations are relatively simple, and many of them are quite similar. For these the training and assignment of operators should cause little difficulty. In almost every plant, however, there are a few operations that require an unusual combination of skill, temperament, and integrity, and the training of such operators may become an acute problem. Hence the routine training for the ordinary operations may well be left to the foremen, but the unusual should receive special attention from the process engineer.

Furthermore, every opportunity should be offered to each operator to increase his skill and value to himself and to the plant. Here, a definite policy, established by the general management and administered by some part of the production engineering staff, might be worth serious consideration.

Wage Incentives

The most effective wage incentive is one that helps to make the individual realize, to a large extent, that he is in business for himself. Conditions are so varied that it is doubtful if any single system of wage incentive will be the most effective for any given plant. Piecework, bonus, group bonus, and many other types of wage incentives have their place.

Furthermore, wage incentives alone are not enough to secure and maintain the full active support and cooperation of each individual operator. Concentration on the mechanical advances and refinements tends to push the human factor into the background, although this factor is as important as or even more important than the mechanical phase.

The problem of wage incentives is one of policy, to be established by the general management and administered by the production engineering staff.

Labor Relations

The subject of labor relations has many aspects, and many books have been written on this subject alone. Among its problems are the following: seniority, promotion, and security; organized labor (union) relationships or individual agreements; a man's right to a job and a man's rights in his job; and the human relationships between the many individuals in an organization. All, except the last, are largely matters of policy which must be established, to a large extent, by the

general management. The last—and the most important—is a matter of individual relationships. Improvements in these may be fostered by the management, most effectively by personal example, and self-centered and individualistic persons may be assigned tasks that do not depend on group effort; but for the most part, results really depend upon the behavior of the individuals. We should realize that some valuable potential creative ability is present in every individual of any organization; the great problem is to develop our personal inter-relationships so that this potential energy may be transformed into kinetic energy. One of my colleagues remarked, when speaking of assistance given him by mechanics in the shop, "Their field of knowledge may be quite limited, but they illuminate a small spot brightly." The responsibility for improving these human relationships rests with every single member of the organization.

Quality Control

The quality of any product is tested by its performance in service. Norman F. Harriman, in his excellent treatise on *Standards and Standardization,* gives this definition of quality: "Quality, in the sense here used, is that which fits a product for a given use. A product is not simply good, it is good for a certain purpose, and the word quality is meaningless apart from the use in view. Good quality means good for a definite use."

Quality in a product does not develop of itself; it must be definitely and consistently striven for. The effort to achieve it must start with the original design, selection of materials, and choice of manufacturing processes; it must continue through all the productive effort, including the assembling and testing; and it must frequently include adequate servicing even after the article is in the hands of the customer. An attitude of "good enough" brings sooner or later a deterioration of quality. Constant effort must be applied to the improvement of quality, always with a view to making the product better for a given use. Changes in design or in processes adopted to reduce costs should always be such as to improve the product.

Quality control during actual production requires a considerable amount of inspection. This inspection may be divided into several phases. For one, we have the preventive measures undertaken to minimize the chances of making mistakes. These include the checking and testing of materials, new tools and machines, and original set-ups. If the members of the production design staff are responsible for the performance of their design, this preventive inspection will logically be their responsibility.

For another, we have the process or floor inspection as the parts progress through the several machining operations. The department foreman is responsible for the accuracy of the work produced in his department so that this inspection may logically be his responsibility also. On the other hand, if a general inspection organization exists, the foreman's responsibility should be exercised through the machine adjusters and other assistants, and the routine process inspection should be done by members of the general inspection staff. This does not mean any divided responsibility; the foreman is still responsible for results in his department, whereas the general inspection staff is responsible for calling to his attention any details overlooked by him or his agents, and for preventing faulty parts from proceeding farther.

Following this, we have the finished-parts inspection to make sure that only correct parts are permitted to flow through to the finished-parts stock room or to the assembly department. This is logically the responsibility of the production design staff.

After assembly, the finished product is often tested for performance, for the making of any special adjustments that may be necessary. Such testing should be logically a part of the responsibilities of the production design staff, possibly supervised or rechecked by the functional design authority.

One advantage of having the production design staff responsible for quality control through production is that this responsibility will keep members of this staff in constant contact with the production staff and with many of its problems; and such contact will tend to eliminate the chasm that seems to exist, unfortunately, in too many shops between the drawing room and the shop.

Such quality control should extend to a study of the performance of the product in the hands of the customers. This might be limited to an investigation of complaints from them; but for adequate product development in the future, definite studies of the performance of the product in the field will prove invaluable.

Maintenance of Equipment

The maintenance of equipment is the responsibility of the staff which uses it. The machine operator or his immediate supervisor is often responsible for reporting the need of repairs. This plan works well in general where there is a single shift of workmen; but when more than one shift is used, the equipment is likely to suffer unless there is a definite organized effort for its maintenance. The responsibility still remains with that part of the production staff which uses it.

Cost Reduction

Cost reduction efforts include the improvement and re-arrangement of the equipment to reduce the productive effort, as well as the introduction of new and improved processes whenever they may become available. In the original selection and design of processes and equipment we should use the best information available. It is obvious, however, that after production has actually started, we learn much more about its unique problems than we knew before. The slogan for cost reduction effort might well be: "No matter how well we have done a job in the past, it is always possible to do it better and more cheaply." The only question is whether or not we are capable of making that improvement. This is a place where the whole-hearted cooperation of the man who does the actual work of production may mean the difference between failure and success.

Cost reduction is the responsibility of the process engineer. He may be attached to the production staff or to the preparation staff. In fact, the same process engineer may be transferred from one staff to the other as press of work may dictate.

Correction and Development of Production Design

The initial production design is nothing more than our first best guess as to the detailed specifications of the component parts of our product that will use the available equipment most effectively, and still retain and, if possible, improve upon the original functional design as regards its performance. If we can learn by experience, it is clear that after production has started, we should know much more about it; and the more extended our experience with it, the more we should continue to learn. In addition, the initial production design represents in general the opinions and experiences of a small group. As production continues, more and more competent persons become familiar with it. Furthermore, even with the best intentions and reasonable care, mistakes will creep in. All these conditions make it apparent that the development of the production design is a continuing process that is never finished. The production design staff is responsible for the correctness of this design, and changes should be made without question as their need or value becomes apparent. If this group is also made responsible for the quality control through production, members of its staff are in constant contact with the progress of events in the shop, and this necessary information will be first-hand knowledge. Otherwise the production group must keep them informed, because a record of these developments is essential, not only to keep the records

up to date, but also to have the benefits of this experience which should be incorporated in any new designs.

Cost Control and Budgeting

Without definite control, the costs of any project tend to mount alarmingly. To keep costs within reasonable bounds, it is necessary to be cost- and time-conscious. Probably the best way to develop this sense of time and cost is to budget the estimated amounts available. Each individual and group should then strive to accomplish its specific tasks within the budgeted allowance. If these budgets must be exceeded, it is good practice to require that requests for additional amounts, with the reasons for making them, be made before the original amount is exceeded. In other words, let each explain before the account is overdrawn rather than make excuses afterwards.

It should be the responsibility of each group involved to give its own estimate, or agree to the estimate made by others, for the time or money required to carry through any project to a definite stage. These detailed estimates form part of the basis of the estimate that is submitted to the general management. From this information, the general management makes its decision, and sets up the actual budget which is to be followed.

We have now considered the more important problems of routine production. For the solution of these, and also of those dealing with preparation for production, many supporting and continuing activities must be carried on, not all of them an integral part of production engineering, but all having a definite bearing on the problem or its solution. A list of these supporting activities is as follows.

Supporting Activities

Standardization

The subject of standardization covers so wide a field that it is difficult to know where to start. It includes the standardization of elementary parts and surfaces, materials, processes, specifications, tools and machines, and methods of test. In one respect, it is the attempt to reduce to routine as many of the elements of engineering as possible. Here, as with routine, these standards are developed to meet the normal conditions—exceptional cases will always need special consideration. Departures from such standards should always be permissible whenever it can be proved that such departures lead to better results than the use of the standards would do.

Standards may be classified under many different headings. Our general engineering standards are formulated under the procedure of

the American Standards Association. The majority of our national engineering societies and trade associations have the subject of standardization as one of their major objectives. Almost every large industrial organization finds it necessary to develop specific standards for its own use; while many of them, particularly those which operate several plants, have set up permanent standardization groups in their own organizations. Practically every government department has its standardization group, and some attempt is made to correlate part of this work through such agencies as the Federal Specifications Board. In fact, the development of the production design is, in effect, the standardization of every component part of the product.

In general, any standard must stand or fall on its intrinsic merits. Any standard, to be adequate, must meet the test of utility and economy. Where an adopted standard is applicable, the chances are that in its formulation it has received far more critical study than any individual designer would be justified in giving to a single detail of design, and hence this analyzed solution available should be much better than an inspirational one that may have come on the spur of the moment.

The formulation of standards ought to be a group effort. All interests involved should be represented: the designer, the producer, and the user. The final solution should represent the best judgment of the group as to the best way of reconciling the requirements of functioning with the limitations of manufacturing processes, so as to obtain the maximum utility at the minimum expense. These standards are subject to revision and improvement as experience in their use and production makes evident the need and possibility of further development.

The responsibility for the use of standards wherever possible may be delegated to a standards engineer, but, to be most effective, a definite standards policy should be established by the general management and receive its constant and whole-hearted support.

Safety and Accident Prevention

As time goes on, more and more requirements for safety and sanitation are being specified by law or required by the terms of liability insurance companies. These represent minimum requirements. Some relate to the construction and use of the buildings and building equipment; some to the arrangement of the equipment, aisles, guards over open belts and gears; and some to safety features on individual machines and the attached equipment. The process engineer must do his part in the arrangement of the equipment or factory layout and in the design of the jigs and fixtures. The responsibility for checking these

conditions may be delegated to a safety engineer on the production staff. His efforts are often checked in turn by periodic inspections of insurance company representatives and inspectors from the state or local government.

In addition to this, there is the problem of accident prevention. This is largely a matter of individual responsibility, but much may be done by organized safety campaigns to bring the individual's responsibility home to him. One plan in common use tries to invoke the spirit of competition between different departments to keep their accident records clear, or lower than any other department. Similar methods are often used to improve the neatness or cleanliness of departments, aisles, stairways, and washrooms.

Manufacturing Capacity Records

In order to plan production effectively, it is necessary to have reliable information of the manufacturing facilities available. This requires not only an inventory of the equipment but also of its actual productive capacity, as well as what part is in use on current production. In essence, it is a matter of bookkeeping, and the clerical work required may be done in an order department, cost-accounting department, or in the production schedules department.

The actual productive capacity of any piece of equipment may be quite different from its potential capacity. When a machine is used for short periods of time on successive lots of different parts, the proportion of time required for set-ups will be greater than when it is used continuously on a fixed set-up for the production of a single part. Even in the latter case, its potential capacity is reduced by the time required to change or to sharpen cutting tools, for cleaning, oiling, and other items of maintenance; so that even with a full-automatic machine, the actual productive capacity may be only from eighty to ninety per cent of the full potential capacity. It is the responsibility of the process engineer to see that such information is collected and properly used.

From this actual productive capacity must be subtracted that part of it already allocated to current production, perhaps leaving a balance which is available for new work. It is the responsibility of the production engineer to see that this information is in the hands of the clerical department which is charged with the responsibility of keeping the records. These records are used by the preparation group in planning new production and by the production group in scheduling current production.

Factory Cost Accounting

The question of purposes and methods of factory cost accounting is a highly controversial one. The accounting for direct labor and direct material costs is relatively simple, but the equitable distribution of the many indirect expenses is, in general, an unsolved problem. It is safe to say that few, if any, large organizations know accurately their true detail costs. As regards the financial accounting, particularly when a single specialized product is involved, this may be of minor importance. For the cost reduction and the production engineers, however, this condition at times is serious, because a change is often made to reduce costs, possibly a re-arrangement of equipment, which reduces the indirect expense, but which, because of the method used to distribute this expense, does not reflect directly the actual saving in a reduced cost record of the part. It should be possible, however, to arrange the cost accounts to serve both the needs of the financial department and the needs of the production department.

Cost-accounting procedure is usually set up by the financial branch of the organization. The information used comes from many sources, including some of the production records. The preparation group has need of considerable statistical information from these accounts to prepare estimates on new products intelligently. The production group should have current and prompt reports from these accounts to know how well it is meeting its budget. The production group is responsible for the accuracy of the information which it sends to the factory cost-accounting department for record.

Time and Motion Study

Time and motion study is a tool used for many purposes, and one on which many books have been written dealing with its technique and use. It may be used to establish a base for an incentive wage payment on some new or altered operation, or as a study to check the effectiveness of new or old equipment, or as a study toward the start of an improvement in an old process or arrangement of facilities, or as a test of the skill and increase in skill of one, or of a group of workmen. The results should serve both the production group and the preparation group. The responsibility for this work rests with the process engineer, who may be a specialist in this particular task.

Labor and Equipment Studies

In too many plants, the accuracy of the work normally produced is a matter of hope rather than of definite information. Many tolerances are established on the assurance of the production department that

they can be readily met, whereas later they must be increased materially to suit the actual conditions. One of the responsibilities of the process engineer should be to make a definite study of the limits of accuracy actually attained under the different conditions of operation, and of the degree of skill required of the machine operator as the requirements become more exacting. The preparation group should have a definite table of tolerances which can be maintained on the different types of equipment, and should be given some intimation of the increased care and skill to be exercised by the operator when smaller tolerances are specified. The effort to meet these smaller tolerances will add to the cost. These studies might also include ways and means of training operators to increase their skill, and with them should be included a tabulation of exact sizes and forms of those elements of the equipment which govern the design and size of fixtures and cutting tools.

Basic Factory Planning

There are many incidental problems connected with any plant layout, such as provision of steam, gas, water, compressed air, or electric power. If special lines must be installed, and connected to some distant source for each new or changed layout, the expense and time may be considerable. There is always the possibility of making such basic or standard factory layouts that any of these installations will follow a general basic plan, with provision for additional outlets near where they may be needed in the future.

In general, there are two arrangements which may be used to locate the machinery in a plant: first, the grouping of similar types of machinery; second, the arrangement of the machines in the sequence in which they are needed to machine a specific component part of the product. The first arrangement is most frequently used when the parts of the product are small, and their transportation from department to department does not create a major traffic problem, whereas the second arrangement is used on large and continuous production of heavier parts. Here we must often treat our parts- and materials-handling problems as a major task. Here too, some general basic plan as a guide will lead to economy and more consistent results.

All these and many other basic details of factory planning could well be the responsibility of the plant engineers' group of the production department. These basic plans, coupled with definite suggestions for the solution of specific problems of the plant engineer, should guide the process engineer in his arrangement of specific shop layouts.

Process Development

The unique requirements of some part of the product may require the development or the material improvement of some manufacturing process. Again, the success of a new product may be largely dependent upon the development of a new process for certain critical operations. The reverse may also be true; the development of a new process may make possible the development of a new product. In addition, we have always with us the problem of finding better ways to do old jobs. Sometimes the expense of producing some part of our product leads to a search for new and improved methods, involving the development of new processes to meet these needs. Such work may be done intermittently by a specially organized group attacking a specific problem. In some plants a definite organized effort is being made continuously to improve existing processes and to develop new ones by a permanent group. This is a part of process engineering, and should be a responsibility of the preparation or experimental group. It should never be a responsibility of the routine production group because routine production and experimental work do not mix, but rather interfere with each other.

The solution of such problems often requires research and experimenting. A laboratory solution may be found which must next be translated into an experimental factory process, and which finally must be introduced into the plant as a routine production process. Care must be taken that such new processes are not forced too soon into the production routine, or the production will become so deeply involved in experimental problems that the production schedule will suffer.

Product Development

To maintain a high quality, any product must be constantly improved. Many large organizations have research laboratories, and a large part of their work is directed towards product development, improvement of the present product and the development of new products. This is particularly true of those industries which had their genesis in the laboratory. This does not imply that all the work in such laboratories is directed for and dictated by commercial motives. Yet even if the commercial exploitation of discoveries is only a by-product, nevertheless these by-products, in the long run, must support the laboratory if it is to continue to operate. The work of such research laboratories may be entirely outside the field of production engineering, but eventually the results of some of this work become part of

production engineering, passing through the hands of the functional designer and the production designer.

Some plants, in addition to research laboratories, have experimental departments. New and improved products are here devised, often a dozen of them for every new product which is adopted for production. Such experimental work is often a part of the problem of functional design.

Besides this, there is a large amount of analytical work, including the critical analysis of many elements of mechanism, such as gears, cams, linkages, mechanics of materials, information and analyses which are invaluable to both the functional design and the production design, but most essential to the full completion of the production design. Such analytical work could well be a responsibility of the production design.

There are two types of design which, for want of better terms, we will call the inspirational and the analytical. Inspirational design alone will give us many new things to think about, but the results will not always be practical, or of any great commercial value. Analytical design alone will give us valuable and practical results, improving quality, reducing costs, and extending the field of usefulness of existing types of products, but it will seldom, if ever, give us anything startlingly new. The best results require the inspirational features tempered by the cold reasoning of the analytical investigation.

One of the tasks for which it is most difficult to budget the time—and keep within the budget—is the design of a new machine. One reason for this is that the designer too often tries to introduce a large amount of new development with the specific task of combining a group of mechanical elements to give the prescribed service. Such specific design should be rigidly divorced from any attempts at new developments of common elements. The designer should restrain himself, and use tried and proved elements whenever possible. The problem of development is another task and should be solved by itself, and should most often be restricted to the study and development of specific mechanical elements, rather than to complete mechanisms from the start. In other words, standards should be developed for all the more usual elements of a given type of product, and these standards should be used.

Performance in the Field

As noted before, the acid test of any product is its performance in the hands of the customer. Despite this, it is surprising how many designers of some products know practically nothing of its actual per-

formance in the use and misuse it receives at the hands of the customer. True, they may be familiar with the conditions and results of tests made in the manufacturing plant before shipping; but many designers of printing presses, for example, know little or nothing first-hand about the problems of make-ready, operating, and cleaning a press as a matter of daily routine. Again, the unguarded remarks of a typist about some feature of a typewriter with which she is struggling might cause the ears of the designer to tingle. We too often assume that in the absence of specific complaints, everything is satisfactory. We might have the young child of a friend visiting us, whose conduct and manners were anything but satisfactory—but only in extreme cases would we complain.

It should be the responsibility of the product design authority either to establish permanent contact with the users of their product, or to make periodic surveys of its use in the customer's plant. Here is by far the best research laboratory for the collection of performance information that exists. A relatively small amount of money spent for traveling expenses can reveal more pertinent information than many times that amount spent in setting up and operating an experimental department to uncover the same information.

Thus the problem of production engineering begins and ends with the product. Our designs, plant, equipment, organization, and all our activities are only means to this end: that we can place in the hands of our customers a product that will steadily and dependably render him some service he wants or needs.

SECTION 1. PREPARATION FOR PRODUCTION

CHAPTER II

PRODUCTION DESIGN

Most of the difficulties met in the initial stages of the production of a new product may be traced back to faults in the production design. This situation is graphically presented in the introduction to an article on "Production Design of Ordnance" by J. D. Pedersen, in the May-June issue, 1935, of *Army Ordnance*, and is quoted by permission of the Army Ordnance Association:

> The elements to be considered in the design of ordnance matériel are essentially the same as those in the design of any similar mechanism when volume of production warrants the most efficient manufacturing equipment. But so far, neither in the production of ordnance matériel nor in industry in general, has adequate study been devoted to designing the component parts with the express purpose of facilitating their mass production. Such study should follow and be a development upon the inventor's design. In this paper it will be called *Production Design.*
>
> It is not our machine tools, nor our knowledge of fixturing and gaging which is generally inadequate. Our weakness, which lies farther back, is in the drawings supposed to specify exactly *what* each component should be. Most drawings depict little more than the simple abstract or idealized component which unfortunately cannot be produced by known manufacturing processes. These drawings fail to state completely the limits of variations which will produce functioning and interchangeability.
>
> This is due to the customary practice of delegating to the draftsman, rather than to an expert production engineer, the responsibility of making the component drawings. Such drawings are frequently dimensioned from some hypothetical center line or other reference point convenient to the draftsman, despite the fact that these points will not be used for locating in fixture and gage during manufacture. In some drawings several different reference points may be found for one component. The result is analogous to that obtained by the amateur workman who, in sawing off boards for a picket fence, uses the most recently sawed picket as a measure for the next, and finds that the final picket has acquired surprising stature. In ordnance matériel no pains should be spared to reduce the design to the forms best adapted to production, and to define precisely *what* each component shall be.
>
> Wars generally come suddenly. They catch us with an inadequate supply, usually with little more than pilot models, of the weapons we contemplate

using. Contracts are let in vast numbers. Factories are improvised and the work on special manufacturing equipment is started. Organizations are hurriedly augmented, necessarily with a large portion of labor and superintendence generally ignorant of the product to be made. There is no time to deliberate on details of design. Action is demanded. Zeal too frequently is substituted for ability. The whole nation is crying for guns, at once. This is exemplified by a picture typical of production during the Great War.

A factory receives production orders and component drawings along with one or more models of the firearm desired. The models function well in themselves, their components readily interchanging from one to the other. But, upon measuring these components, it is found that in many particulars they do not agree with the drawings nor among themselves. Frequently the drawings carry tolerances difficult to procure under mass production methods. Attempt is made to reconcile models and drawings and finally to establish production or manufacturing limits. Correct limits are applied easily enough in the case of simple male and female engagements; also in the case of surfaces requiring only an "atmospheric fit." However, in the attempt to determine the tolerance accumulations in a functional train involving several components we begin to bog down. Accumulated variations mount up alarmingly, and many tolerances are set which later prove unfeasible. The main fault is the *arbitrary* setting of limits which later fail to produce either interchangeability or functioning.

Many tolerances are set at "round table" conferences. The inventor groans if a variation of more than a thousandth of an inch is suggested, while the milling department foreman fights for ten times that amount. However it may be, tolerances *are* set, component drawings brought up to date and the special equipment of fixtures, gages and cutting tools designed and built. So far, in spite of many small difficulties, all has seemed fairly clear sailing, and hope is strong that the impending production schedule will be met.

As delivery begins on the special equipment, the fixtures are set up on their belted machines and tried out. Certain operations do not produce to gage. These require changes. Certain other operations produce to gage only by careful "nursing" of the operation. "Let's go—we must meet the production schedule." Finally, the first components seem ready to assemble.

In the assembling department, however, the sins of faulty production design now overtake us. Some parts will not assemble without being changed; affected surfaces are outside their gage limits; other components will not assemble, although they are everywhere within their gage limits. A few guns may assemble without special adjustment, but they do not perform satisfactorily the required functions. Apprehension justly arises that the components have not been correctly specified. But, the head office continues to be cruelly insistent about "guns in the shipping cases."

We now begin to realize the import of the word "trouble." A detachment of "trouble shooters" is hastily organized, many suggestions considered, some adopted, and changes to equipment are started. The production schedule has already been "badly bent" but hope lingers that by extra effort we can yet

swing in with the final quota. The necessity of frequent "explainings" to the head office does not add to our peace of mind or ability to secure results. Yet important decisions must be made, for—to continue machining may accumulate a mass of useless components—to stop will result in no components for the assembling department to practice upon. During the "tuning up" stage, machining on certain components may be stopped and started several times.

Eventually, the components carrying the newly adopted changes come to the assembling. The original troubles seem settled. But now new ones crop out, some as an unexpected result of recent alterations. The necessity of yet more changes develops from time to time. These are made. Matters are improving however, as one by one the troubles are run down.

After much travail, one day it is realized that routine assembling may be started. This soon grows into "guns in the warehouse" in increasing numbers. But many extra months have elapsed and an entirely new production schedule must be set up since there is no hope of meeting the original one. During the entire course of the production, difficulties frequently arise, but we are now more proficient in solving them.

In cases where contracts for the same product are let to several factories, the output of one plant becomes differentiated from that of the others since each factory has its individual troubles and, usually, its own solutions.

Many who have participated in the above picture have concluded that the production travail described is unavoidable. A thorough survey, however, indicates otherwise. We now know that the net result of the changes made was finally the *adoption of attainable tolerances with limits adjusted to secure interchangeability*. But, groping in the dark of cut-and-try methods is time-wasting, costly and inconclusive! Nearly all of these troubles and delays at the start of and during the course of manufacture may be avoided by a competent production design of the components. The feasibility of such a design has been demonstrated more than once.

In spite of our competent methods of machining and gaging, the neck of the production bottle still lies in deficient production design. The best plans of organization for mass production may either be emasculated or made effective by the degree of excellence entering into the design of the matériel required. Nor is there any substitute for an early start. When war involves us the immediate availability of precise specifications for ordnance may well be the deciding factor.

Adequate production design requires the services of the ablest and most experienced production engineers available. The engineer must study the proposed product and become thoroughly familiar with its functioning and purpose. He must bring to this task a knowledge of

production processes and their limitations as regards the accuracy of attainable results. This could well be reinforced by definite statistics of past results of accuracy attained in the specific plant involved. He should be familiar with engineering standards and standardization because this production design itself is, in large measure, a problem of standardization. Above all, he should have a full understanding of the principles and technique of dimensioning with tolerances.

The component drawings themselves should be made by competent draftsmen, but the production design engineer should give him the specific instructions needed, as well as check personally to see that these instructions are correctly carried out. In giving these instructions, it would be well if he also pointed out the reasons for them, thus teaching the draftsmen that the location of dimensions and the extent of the tolerances are not matters of personal convenience or chance, but that every item of information on these component drawings is essential to meet a required objective, and that the manner in which it is given has a vital influence on all succeeding work of production. By so doing he will increase his own understanding of the subject and improve his own technique, because the best way to master any subject is to try to teach it to some one else.

Tolerances are necessary evils, and are required only because of our inability to produce identical parts. The application of tolerances to the dimensions of the component parts has introduced problems which, as yet, have not been fully solved. Even today, after nearly forty years' experience with them, there is no common understanding as to their interpretation in different manufacturing plants. It is even worse when, in the same plant, the engineering department and the shop mechanics are not in full agreement about such interpretations.

The first essential to understanding and possible agreement on any subject is a definition of specific terms. We will therefore define some of the terms which will be used in the present discussion. The meanings of these terms will be here restricted to the definitions given.

Tolerance. The amount of variation permitted (or tolerated) in the size of a part.

Allowance. An intentional difference in size in the dimensions of mating parts. It is the minimum clearance or the maximum interference which is intended between mating parts. It represents the condition of the tightest permissible fit, or the largest internal member mated with the smallest external member.

Basic size. The theoretical or nominal standard size from which all variations are made.

Limits. The extreme permissible dimensions of a part. The maximum

limit is the largest permissible dimension; the minimum limit is the smallest permissible dimension.

Maximum metal size. That limit which leaves the most material on the part.

Minimum metal size. That limit which removes the most material from a part.

Example: A 2-inch diameter shaft and bearing which must have not less than 0.002-inch clearance between them to meet operating conditions, while the size of each member must not vary more than 0.001 inch.

The tolerance on both members would be 0.001 inch.

The allowance would be 0.002 inch.

The basic size would be 2.000 inches.

The limits depend upon the manner in which we apply the allowance. Here we have two schools of thought. One applies the allowance to the size of the shaft, holding the minimum limit of the bearing to the basic size. This practice is often referred to as "minimum hole basic." The argument for this practice is that the sizes of the finishing tool and gage are non-adjustable for the external member whereas those for the internal member are generally adjustable; hence this practice leads to the greatest economy. This contention, however, does not always hold true as the sizes become larger.

The other school of thought applies the allowance to the size of the bearing, holding the maximum limit of the shaft to the basic size. This practice is sometimes referred to as "maximum shaft basic." In this case, the contention is that many of the internal members, such as cold-rolled shafting, driving shafts of motors, gear reducers, and other machinery are purchased, and are to be used without further machining. Therefore any allowance for the conditions of fit that may be required must be made in the size of the mating external member.

The militant advocates of either practice appear to feel that, because their own practice meets their particular needs best, it should be used in all cases. It seems, however, that there is need of both, and that the specific conditions should dictate the choice. The minimum hole should be of basic size in all cases where the use of standard, non-adjustable tools represents the greatest economy. This condition most often exists where the same factory machines the mating surfaces of both members of the pair. The maximum shaft should be of basic size in all cases where the use of standard purchased material without further machining represents the greatest economy, even though special tools are required to machine the mating part. For the larger sizes, when the tools for both members are adjustable, neither practice may have any inherent advantage over the other, either functionally or economically.

For this example we will make the minimum size of the bearing 2.000 inches and apply the allowance to the shaft, whence:

Minimum limit of bearing will be 2.000 inches.
Maximum limit of bearing will be 2.001 inches.
Maximum limit of shaft will be 1.998 inches.
Minimum limit of shaft will be 1.997 inches.

The tightest fit is when the mating members are both of maximum metal size. This is a terser way of saying that the tightest fit is when the bearing to the minimum limit mates with the shaft to the maximum limit. Conversely, the loosest fit is when both members are of minimum metal size.

Other differences of opinion relate to the method of expressing the permissible variations on the component drawings. This may be done in any one of several ways. At the present time there are three methods in more or less general use. These are as follows.

Bilateral Tolerances

When tolerances were first introduced on drawings, some forty years ago, the first practice was to express a permissible variation on every dimension as it stood, without regard to the relative importance of the different dimensions and with little or no thought to their positions or relative relations. Most of these tolerances were expressed as plus and minus. Thus if the dimension were 1.500 inches, it was given as (1.500 ± 0.001), or with whatever tolerance was believed to be suitable. Experience soon indicated that the problems introduced by the presence of tolerances on component drawings were more complex than had been assumed. Nevertheless, many engineers still believe that the average, or mean, dimension should be given, followed by a plus and minus tolerance. For the shaft used in the preceding example, the diameter would be given as (1.9975 ± 0.0005). Frequently the original tolerances represent nothing more than a first guess as to what is needed and what may be secured. If difficulties arise in production, and a greater tolerance can be permitted, the tolerance is changed. To reduce the work of the draftsman in changing the drawing, the original average value remains unchanged so that the revised notation would be ($1.9975 \pm {}^{0.0005}_{0.0010}$). In such cases, the original average value would be meaningless in itself. A plus and minus tolerance should be used only where a variation from a fixed dimension is equally dangerous in either direction, and here a plus and minus tolerance of the same amount should be given. If the tolerance were changed, it would still remain plus and minus an equal amount. In all other cases, the use of plus and minus tolerances is distinctly bad practice. Such tolerances are commonly known as bilateral tolerances.

Unilateral Tolerances

If the initial dimension placed on the drawing represented the size we would use if it were possible to produce it exactly, then a little study of the operating conditions of the pair of mating surfaces would show that a variation in one direction would often be more dangerous than a variation in the opposite direction. In such cases, the tolerance would be given in the less dangerous direction. This type of tolerance is commonly known as a unilateral tolerance. If the same shaft is used as an example as before, the initial dimension for its diameter would be 1.998 inches. If this size were larger, we would be encroaching on the clearance required for the oil film and would soon be in difficulties. If it were smaller, the permissible clearance would be increased, and this is less dangerous provided this clearance does not become excessive. This dimension would then be given as ($1.998 \pm {}^{0.000}_{0.001}$). This notation means that if it is possible to work to exact dimensions, the size should be 1.998 inches. It must not be larger. If there is any variation, it must be smaller, but it must not be over 0.001 inch smaller. This notation for tolerances is commonly used on medium- and large-sized parts where the control of size is, to a great extent, checked by standard measuring instruments, also where the component drawings are actually used at the machine.

Limiting Dimensions

When parts are made in large quantities, when every machining operation is completely tooled, and when a full complement of gages is provided, the component drawings themselves are seldom used on the production floor. These drawings are used primarily by the tool and gage designers and inspectors. Here the limiting dimensions are the ones generally required. As the component drawings should be made to suit the use to which they are put, under such conditions, the drawings should give these limiting dimensions. If we continue to use the same shaft as an example, its diameter would be given as ($\begin{smallmatrix}1.998\\1.997\end{smallmatrix}$). In general, this practice is followed quite extensively for the smaller parts, and for some of the larger products made in large quantities.

Interpretations of Tolerances

Another perplexing problem yet to be solved is that of a uniform interpretation of the meaning of tolerances on component drawings. Most of this difficulty can be traced back to the fact that no measurement is ever correct in an absolute sense. The probable errors may be of the order of a small fraction of a thousandth of an inch, sometimes even less, but they are always present and are always troublesome.

As noted before, tolerances are necessary because of our inability to produce identical parts. These unavoidable manufacturing variations come from a variety of sources, such as

(*a*) Inaccuracy of work-holding devices.

(*b*) Inaccuracy of adjustment, or set-up.

(*c*) Inaccuracy of machines, such as deflection under stress of cutting, eccentricity of revolving parts, and misalignment of spindles and centers.

(*d*) Inaccuracy of both the size and the form of cutting tools.

(*e*) Wear of cutting edges of tools.

(*f*) Shifting of position from original set-up, wear of locating surfaces.

(*g*) Inaccuracy of gages and other measuring tools.

(*h*) Wear of gages and other measuring tools.

(*i*) Improper location of work because of chips, or insufficient tamping after clamping, etc., i.e., human factor.

As will be noted, many of these variations are caused by initial errors in the equipment. With a given tolerance, the more that such initial errors can be reduced, the greater is the remainder of the tolerance which will be available to cover variations caused by wear and by the piece-by-piece handling of the component parts of the product when it is mounted into the productive equipment.

To me, the only logical and consistent interpretation of the tolerance is that it is the permissible variation allowed to cover all variations, whatever their cause or nature. This interpretation puts a premium upon reducing the initial errors in all the equipment as much as possible so as to leave more of the tolerance for the continuing and unavoidable wear on tools, cutters, and gages, as well as for the ever-present human factors of operation. The extent of the tolerance should be as great as the correct functioning of the product will permit. Such an interpretation demands that any variation in the size of the gages must be within the limits of the component part.

Many production engineers and mechanics argue that the whole tolerance should be available for the manufacturing department, so that any variations in the sizes of the gages must be outside of the product limits, else these gages will reject parts which are close to either limit. When the work is controlled by limit gages, the size of the product will follow them. In fact, where limit gages are used, the physical sizes and forms of the components will depend more upon the sizes and designs of these gages than upon the dimensional specifications on the component drawings. Thus a radical change in the design of a gage, without any change in the dimensional specifications, may

require an entirely new choice and sequence of machining operations to produce the same component part.

Another argument is sometimes advanced for making the sizes of the gages outside of the product limits. The claim is made, for example, that a one-inch diameter plug gage will not enter a one-inch diameter hole; hence the "go" gage must be made something smaller—the amount smaller may be another source of argument—than the minimum limit of the hole in order not to reject it. The question as to the actual size of a hole is still a matter of some doubt. For all practical purposes, however, a one-inch hole is one that fits a one-inch plug gage. In addition, the persons who argue for a smaller size for the go plug gage often contend that the "not go" gage for a hole should be made larger, or outside the maximum limit because if it is made to size it enters a hole at the maximum limit. Both arguments cannot be valid, but it appears to be impossible to convince such individuals that one contradicts the other.

This practice, nevertheless, is followed in many places; and the gage variations are outside of the product limits. If, however, the limits of functioning parts are known, then the limits on the component drawings must be reduced by the amount of the gage tolerances. Furthermore, it seems illogical to make such conditions that any improvements in the accuracy of the measuring reduce the actual working tolerances of the shop, yet that is just what this practice does. The size of the work follows the size of the gage; and improvements in the accuracy of the gages will keep them closer than before to the reduced tolerances on the component drawings.

Still another interpretation of the meaning of the tolerances is sometimes made. This is primarily a matter of expediency. Expedients are often necessary, but possibly they are used too frequently throughout the whole course of the production since they should always be only emergency measures and not standard practice.

The maximum metal sizes are generally the more important ones, and are the ones most readily determined. Experience or simple experiments will soon give us the tightest conditions of fit which will permit correct functioning for the new product. The minimum metal sizes, which control the loosest conditions of fit, are often indefinite. In this case, we must consider not only the performance of the new product but also its behavior when worn in service. The minimum metal size is therefore specified often well inside the extreme limit of functioning.

In this third practice, the variation in the size of the go gage, which always checks the maximum metal size, is kept within the product

limits because any variation in the direction that makes for a tighter fit soon leads to trouble. Then, in order to avoid arguments in the shop, the variation on the not-go gage is placed outside the product limits. In this case, if the argument is raised that the permissible variation in the size of the go gage is robbing the shop of some of its tolerance, it is pointed out that the variation in the size of the not-go gage gives back all that is taken on the go gage.

We shall stand on firmer ground if we agree that the tolerances on the component drawings shall include all variations in the sizes of the gages, as well as every other existing variation in manufacturing. To the charge that the shop is robbed of manufacturing tolerances when the variations in the sizes of the gages are kept within the product limits, can be returned this challenge: Find a better means of measuring that will leave more of the total tolerance for the use of the actual production. This has been accomplished in many instances by the development and use of comparators which can be frequently checked and reset to very accurate test pieces, so that the amount of the tolerance consumed by the variation in the gage is practically eliminated.

Dimensioning with Tolerances

The correct dimensioning of component drawings with tolerances requires careful study of the functional inter-relations of the many component parts, the application of a definite technique, and continuous practice and experience. No single component can be studied by itself and dimensioned correctly without reference to its companion parts. Above all, the information given must not be contradictory or ambiguous. It should convey the same meaning to all the other people who must use and rely upon it that it has in the mind of the production design engineer who sets it down, but this is no easy task. It is almost impossible to convey or transmit an idea from one person's mind to another's without the person who receives the information unconsciously adding to it something of his own opinions or something from his own experience. It would require an entire book devoted to the subject of production design to present this problem adequately.

There are, however, five basic rules for dimensioning with tolerances which, if followed, will minimize the mistakes; and which, if violated, will inevitably lead to difficulties. These may be stated as follows:

First Rule for Dimensioning with Tolerances

Only one dimension in the same straight line can be controlled within fixed limits. This is the distance between the cutting surface of the tool and the locating or registering surface of the part being ma-

chined. Therefore it is incorrect to dimension any point or surface with tolerances from more than one point in the same straight line. Violations of this rule lead to many contradictions. The different positions, or limits, established by using one combination of such dimensions are quite different from those obtained by using another chain of dimensions and tolerances. If a mistake is made in tool design or in production, and it is possible to work through any combination of dimensions given to justify this mistake, such a justification will be raised and defended even though the particular combination used for defense was not discovered until after the fault.

The application of this rule to the simpler problems of position and size of simple elementary surfaces is comparatively easy. When we must deal, however, with more complex forms, such as profiles, which require several dimensions to define them, then the casual introduction of tolerances to each of the necessary dimensions leads inevitably to a violation of this rule. This rule may be stated in another way. After the component drawing has been completed, it should be possible to make one, and only one, layout of the maximum metal conditions. It should be possible to make one, and only one, layout of the minimum metal conditions. If these layouts were made to an enlarged scale, and the two layouts were superimposed, a generally parallel zone of variation should be present on all surfaces, except perhaps on the registering surface. If a few of such layouts are made, it is soon apparent that there are, at times, some dimensions which should be given without tolerances. Take a taper, for example. If a fixed diameter, without a tolerance, is given at some place along the taper, and the distance to this position is dimensioned with a tolerance from the required locating point or registering surface, then the lines representing the taper, drawn through the fixed diameter in the two limiting positions, will give two parallel lines. These two parallel lines represent the specified limits of the taper and show the cumulative tolerance of both size, position, and angle of the taper. If the permissible variation in the position of the taper is relatively large, and the accuracy of the taper or angle is most essential, then a further specification should be given defining the permissible variation in the angle of the taper itself.

Such cumulative tolerances are frequently used to avoid violation of this first rule. For example, variations in the diameter, form, and lead of screw threads are generally specified in this manner in terms of the pitch diameter. This pitch diameter is the one where the width of groove and the thickness of thread are both equal to one-half the pitch of the screw. This thread form, drawn on the two limiting pitch diameters, gives parallel lines, the distance between which represents

the cumulative tolerance on diameter, lead, and form. When screw threads are checked on an optical comparator, the shadow of the screw thread must lie between the parallel lines drawn on the screen; these lines are drawn to agree with the specified limits of the screw thread.

Irregular profiles are often checked with dial indicators or other means of comparison against a master profile. Here the measurement is one of the amount of departure from this master form. The simplest way to give this information on the component drawing is to specify the basic form with dimensions without tolerances, together with the direction and amount of the permissible variations from this basic profile. In fact, as our component drawing specifications are primarily our gage specifications, there is no reason why, when the gage requirements are the simplest to express, the gage specifications should not be the means to specify these requirements of the product.

Second Rule for Dimensioning with Tolerances

Dimensions should be given between those points or surfaces which it is essential to hold in a specific relationship to each other. This applies particularly to those surfaces in each plane which control the location of other component parts. Many dimensions are relatively unimportant in this respect. It is then good practice to establish a common locating point or surface in each plane and give, as far as possible, all such dimensions from these common location points. The locating points on the component drawings, the locating or registering points used for machining the surfaces, and the locating points used for measuring and gaging must always be identical.

Some texts on tool design begin by saying in effect: "First select some convenient locating point, . . ." If the component drawings are correct, the position of the specified dimensions definitely gives the correct locating point, and the tool designer should not be permitted to use any other. If the designated locating point is inconvenient, and a more accessible one is available, and if the dimension in question is not a critical one so that the position of the dimension can be changed safely, the component drawing should be changed. This is part of the purpose of the production design—to reconcile the design as far as possible to the problems of manufacture. But if it is an essential relationship, then the tool design must follow the specification as given, despite all difficulties. In every case, the locating point used must agree with the position of the dimensions on the component drawings.

Violations of this rule are probably the most common. An examination of the changes on component drawings which have been made during the first few months of the production of a new product usually

shows that the majority of these changes have been made to correct the position of the dimensions. If the reason for the change is given on the change slip, it usually reads, "to facilitate manufacture," a reason which may cover a multitude of sins. For instance, the pinion for an airplane propeller drive had a shoulder against which was assembled a ball bearing. This bearing was held in position by a threaded collar, on the outer end of which were holes to match some companion holes in the hollow stem of the pinion through which a wire was threaded, to prevent the loosening of the threaded collar. The dimension for the location of these holes in the hollow stem of the pinion was originally given from the end of the stem, which was an "atmospheric fit" with liberal tolerances. The drill jig was made accordingly, locating on the end of the stem. Because of the large tolerances between the locating shoulder for the bearing and the end of the stem, and because of the cumulative variation of the width of the bearing and that of the threaded collar, the holes in the threaded collar did not line up well with the holes in the stem of the pinion and much difficulty was experienced in trying to thread the wire through the two sets of holes. On looking at the drawings with an awakened eye, it was easy to discover the trouble, so the dimensioning on the drawing of the pinion was changed: these wire holes were located from the locating shoulder for the bearing. This required the making of a new drill jig, then the trouble was cured. If the second rule had been observed in the first place, all this would not have happened.

As another example, the crankshaft for a new eight-cylinder automobile engine went into production. The wrist pins in the piston were lubricated by oil, fed in through the crankshaft and out through a hole in the middle of the crank bearing or connecting-rod bearing which was matched by a hole running up through the connecting rod. Shortly after the first of the new engines was assembled and was being tested on the test stands, it was noticed that the wrist pins in the last two or three cylinders were not receiving enough oil. When the connecting rods were disconnected, it was noted that the oil hole was not in the middle of the connecting-rod bearing of the crankshaft on the last few bearings. An examination of the drawing for the crankshaft showed that the dimensions for the axial location of the connecting-rod bearings were given as a series: the second located from the first, the third located from the second, etc. The gages were made accordingly. In setting up for the machining of the crankshaft, the tools for the first connecting-rod bearing were adjusted to the gage which registered from a shoulder at the front of the crankshaft, corresponding to the dimensioning. The tools for the second bearing were then adjusted to the

gages which registered from the first bearing, and so on. As all the oil holes were drilled in one setting, which meant a common locating point for them all, this locating point was the same shoulder that was used to locate the first connecting-rod bearing. With the cumulative variation in the position of the eight connecting-rod bearings, plus some center bearings, plus the thicknesses of the crank cheeks which were also dimensioned in this series, the results obtained should have been expected. The component drawing was changed by locating each connecting-rod bearing from the same shoulder at the front of the crankshaft as was used for locating the oil holes; new gages were designed and made; and the setting of the machines used for finishing the connecting-rod bearings was readjusted to the new gages. Incidentally, the tolerance for the position of each connecting-rod bearing was increased considerably. This also corrected a trouble which should never have occurred.

Such examples could be multiplied indefinitely, on parts both large and small. Many similar conditions continue to exist without detection and correction, and any initial trouble is corrected by reducing the amount of the tolerance on each dimension involved in the series until their sum lies within the functioning requirements of the mechanism. This is an expensive cure. If two dimensions are involved, then each of them must be held to one-half the tolerance that could be used if the dimension were given directly between the most essential points. If three dimensions are involved, then three operations must be held to one-third the tolerance, etc., instead of one operation held to a tolerance three times as great.

Third Rule for Dimensioning with Tolerances

Every part of a mechanism must be located, or controlled in three directions or planes. Every operating part must be located with proper operating allowances. After such requirements of location are met, all other surfaces should have liberal clearances.

Violations of this rule are common, and lead to troubles which often appear obscure. The location of a part will be determined by the first contact it makes with its mating member, whether this contact is the one desired or not. The only answer is to decide on the best locating surface and provide liberal clearances between all other surfaces that approach each other; otherwise the relative position of the mating parts may always be a matter of uncertainty. All interferences in operation are caused by insufficient clearances between non-cooperating parts.

Fourth Rule for Dimensioning with Tolerances

The initial dimensions placed on component drawings should be the exact dimension that would be used if it were possible to work without tolerances. Tolerances should be given in that direction in which variations will cause the least harm or danger. When a variation in either direction is equally dangerous, the tolerances should be of equal amount in both directions, or bilateral.

If limiting dimensions are given on the component drawings, these should be established in the same manner. In fact, regardless of how the dimensions are expressed on the component drawings, it is good practice to set up the nature and amount of permissible variations from the initial dimension and the direction and amount of variation, and keep this information for record and reference. If changes are necessary, such a record will prove invaluable in checking clearance conditions and the effect of any proposed changes.

Fifth Rule for Dimensioning with Tolerances

The initial clearance, or allowance, between operating parts should be as small as the operation of the mechanism will permit. The maximum clearance may be as great as the proper functioning of the mechanism will permit. The difference between these two values of the clearance gives the sum of the tolerances for the mating parts.

The tolerances given are too often based on hope rather than on definite knowledge. This keeps them too small. They should be based upon the actual functional requirements of the product. Since they are not, many tolerances must be increased in the course of production. Probably about one hundred tolerances are increased for every one that may be reduced. The argument is raised that if larger tolerances are specified, the shop standards will be lowered. I believe that liberal tolerances, rigidly enforced, actually improve the shop standards; whereas very close tolerances, which must often be exceeded to keep the production going, act to destroy the chance of having any shop standards of accuracy.

A critical examination of almost any mechanism will show that there are a few essential surfaces which must be held to small tolerances in order to obtain the desired performance of the product, but that the larger number of the surfaces are of secondary importance in this respect. One object of the production design should be to develop the design so that the number of such critical surfaces are not only reduced to a minimum, but also concentrated on as few component parts as possible. This leads to the simplification of design.

When the tolerances are determined from the limits of parts that

will meet all functional requirements, we have a few dimensions with small tolerances but the majority of them with more liberal tolerances. To some extent, the amount of the tolerance is a measure of the relative importance, functionally, of the surface in question. Under these conditions, the relative importance of the several surfaces will be more evident from the start, and we can devote the additional attention to the critical points that need it most, not dissipating our energies indiscriminately over both essentials and non-essentials. In the first case, we can produce a higher quality product with less effort: in the second case, if all tolerances are exacting, we shall actually produce a lower quality product with more effort, and at a higher cost.

Dimensions of Forms

It frequently happens that we have dimensions of forms, such as the radius of a fillet, where the specification of a tolerance will set up a condition that may be hard to check in production, and mean little or nothing as regards the functioning. We then can specify these conditions as (max.) or (min.) as the case may be. For example, there is a radius at the end of the bore of a ball bearing. Hence any radius between the bearing seat and shoulder on the shaft must be smaller than that at the end of the bore of the bearing in order to avoid interference. To meet this condition, the radius at the end of the bore may be specified as (0.080 rad., min.) while the radius of the fillet joining the bearing seat and shoulder may be specified as (0.060 rad., max.). It is comparatively simple to determine whether the radius of a fillet is larger or smaller than a specified radius, but it is much more difficult to measure the precise radius to determine its exact size.

Again, if the fillet on a part is needed to reduce the stress concentration, and this fillet does not fit or assemble into any other component, then it may be specified as, for example (0.500 rad., min.). On the other hand, if it must not be less than a certain value because of the stress concentration, and cannot be more than a certain value because of assembly conditions, then the limiting values must be given, and the radius must be checked in production with limit gages to make sure that the limits are maintained.

Many similar cases will be met. For example, only the minimum major diameter of a tapped hole is specified. This insures interchangeability with the screw. Its extreme maximum size is limited by the diameter where the thread form on the tap comes to a point, but the crest of the thread of a tap is often the first part of the cutting edge to break down, and the width of flat at the crest of the thread of the tap is kept as great as possible to help resist this breaking down.

There is therefore no need to specify a maximum major diameter for the tapped hole. Furthermore, even if it were specified, it would seldom, if ever, be measured. Specifications of limits which will not be measured are not only unnecessary but foolish.

The presence of a dimension on a component drawing without a tolerance should never be interpreted to mean that no variation is permissible. It should mean that either the possible variation of the position or surface dimensioned is controlled by other correlated dimensions, (such as a cumulative tolerance) or that the surface is of so little importance that no effort has yet been made to determine definite limitations. In all this work, our effort should be to start with the more essential features, and complete them; then to take up the others, as far as possible, in their order of importance. It may be that press of circumstances will not give us the time or the opportunity to cover everything completely. If the neglected items verge on the realm of non-essentials, it is a generally safe practice to let them take care of themselves. Even on these, however, if any question about a specific item comes up, or if any trouble arises in the shop, that item should be taken care of, then and there.

Example: in one plant it was the practice to specify the size of an unimportant drilled hole by giving the drill number and its diameter. The general understanding was that any hole produced by a stock drill of the size specified would be adequate, regardless of the exact size of the drilled hole. Thus a drilled hole was required to hold the end of a coiled wire spring. The diameter of the wire was about 0.040 inch. The hole was specified as (Drill No. 52 – 0.0635). A dispute arose between the inspector and foreman of the department where these holes were drilled. This difference was about an entirely different matter. A new lot of these parts came up for inspection shortly after this dispute, and the inspector tested these drilled holes with a plug gage about one-thousandth of an inch larger than the specified size of the drill. As this gage would enter all of the drilled holes, he rejected the entire lot as oversized. To prevent this from happening again, and to give the inspector something to think about, the component drawing was revised to read $\left(\text{Drill No. 52} - \frac{0.060}{0.090}\right)$, with the revision to take effect at once. The lot was returned to the inspector, and passed without any more criticism.

Use of Standards

One of the objects of the production design is to make use of as many standard parts and surfaces as may be available and suitable.

This might also include the use of some part of another product that is already being manufactured. To do this effectively, some list or book of available standards should be at hand.

Many designers seem to have definite objections to the use of standards. They feel that the enforced use of standards is a definite restriction of their own originality. If standards of design are restricted to elementary parts and surfaces, their use imposes no restriction on the creative efforts of the designer, but instead gives him a greater opportunity for this creative effort, because such standardization reduces to routine the problem of the design of these elements. There is no great originality involved in deciding the form and number of threads to use on a one-half-inch bolt, for example. There are cases, however, where because of unusual conditions, a departure from a standard may be of definite advantage. Then the standard should not be used. One effective practice is to permit the designer to depart from the standard, provided he can demonstrate that the use of the special design will be more effective than the use of the standard. If he cannot do this, then the standard must be used.

The use of standards greatly reduces the amount of work needed to complete the component drawings. Instead of specifying in detail all the dimensions and tolerances of the standard surface, only a reference to the specific standard is required. Copies of these standards should be in the hands of all departments or sections which use the component drawings. Then, as improvements and changes are made in the standards themselves, no change is required on the component drawings. For example, if a 3/8 — 24 tapped hole is required, the notation should be (3/8 – 24 – NF – 2). This would specify a class 2 fit in the fine thread series, and the sizes and tolerances or limiting sizes for major, pitch, and minor diameters would be found in the standard specifications. In some cases, it might be desirable to add the tap drill size. In this case, for all normal conditions, it would be (Tap drill No. "S" – 0.3480 inch). If the depth of the hole were small, such as for a tapped hole in sheet metal, then a greater depth of thread form, requiring a tap drill of smaller diameter, might be needed and should be specified. On the other hand, if the tapped hole were deep, and it was to be produced on an automatic machine, a larger diameter of tap drill might be required to reduce the amount of breakage of taps in production. A larger diameter of tap drill should then be specified.

The greater use of such standards reduces the amount of work required to make the component drawings, the amount of detail imposed on the tool and gage design, and the work of tool making itself, because many of these general engineering and trade standards are made and carried in stock by manufacturers of gages and small tools,

and can be bought in the open market at less cost than that of special made-to-order tools. There is also a saving in elapsed time in securing these standard tools as compared with that needed to obtain special ones.

Many elementary standard parts are manufactured by organizations specializing in that particular type of work. Hence these parts may be purchased at much less cost than they could be made in a factory not specializing in that product. In addition, with the specialized equipment and technique of these manufacturers of specialties, they can also produce similar products, to the special designs of individual manufacturers, better and cheaper than the customer could do for himself. This also holds true for some of the elementary parts required in tool making, such as cutting tools, jig bushings, and die sets.

Specification by Functional Requirements

There are many conditions which a component part must meet which cannot be specified simply or always adequately by dimensions alone. Sometimes it is a question of performance by such a part as a spring. The physical sizes may vary greatly without interference with other parts, but the pressure exerted by this spring may need to be held within close limits. There is no method of dimensioning which alone will insure or specify adequately such conditions. For these and many kindred problems the simplest and most effective practice is to specify the performance required.

A spring, for instance, may be required to assemble into a hole. Here, a maximum outside diameter alone may be all that is required for the dimensional specification. Or it may be mounted on a shaft or rod, with all the world to wander in as regards its outside diameter. Here the minimum inside diameter may be the only dimensional specification. Its performance should be specified as the pressure exerted, with limits for these pressures, at two different lengths. For a compressed spring, the solid height, with limits, may be required. The exact size of wire, number of coils, free height, etc., are all incidental. Such information may be of help in developing the original spring, but this would be a matter of information and not a definite specification.

Again, we often meet certain problems of alignment when the actual amount of run-out between two or more surfaces is not the deciding factor. Here it is the over-all composite condition, involving the actual diameters of the shoulders in question. To check this condition, we can devise such a gage that if the component part enters it, these conditions of relative position will be satisfactory. This may require a more or less elaborate gage, and we can design the gage and place a

note on the component drawing to the effect that these conditions on the part must satisfy that particular gage. When it is a question of simple run-out, a note specifying the maximum run-out between the surfaces in question will be sufficient.

A similar condition exists in the specification of straightness. For example, we might have a quarter-inch diameter tie rod of some length, where some specification of straightness is essential. Assume the length to be four inches and the size of the hole through which it is assembled to be 0.266 inch. We can specify that this tie rod must slide, of its own weight, through a ring gage 0.266-inch diameter (or something less if there is a similar question of straightness of the hole in the mating part) which is four inches long. Any condition of bending that does not prevent its free passage through such a gage is immaterial.

We may have a similar hole twenty inches deep, and specify a plug gage of some smaller diameter and a length of, say, six inches, which must pass through freely of its own weight. The length and diameter of this plug gage should be determined from the conditions of straightness required.

Such conditions should be accepted as a challenge to our ingenuity and analytical ability. We must express the required conditions in terms which can be definitely checked, which will insure the results essential to the performance of the product, and which will be understood in the same way by every one who uses them. These component drawings are the major guide to direct the cooperative effort of a large group to a definite goal.

Specification by Size and Shape of Tool

Sometimes we are confronted with a condition that can be expressed most simply and effectively by giving the size and form of the cutting tool together with its setting or relation in respect to the part being machined. One of the more common conditions is that of the form of the thread of a worm which meshes with a worm gear. A common practice is to specify the thread form in the axial section. Another practice is to specify the form in the normal section or normal plane. Yet there is no normal plane to a thread form because the helix angle of the thread changes with the diameter, hence any one plane can be normal to the thread at one diameter only. The surface which would be normal to the thread would be a warped surface. This cannot be drawn on a plane, and even if it could it would be valueless because the thread form actually obtained in production depends upon the form, size, and position of the cutting tools used to produce it. As these forms change with every change in the type of tool and its position,

the only practical way of obtaining definite results is to specify these conditions of the cutting tool.

If the worm thread is to be ground, the form, diameter, and angular setting of the wheel should be definitely specified. We then take the form of thread that results. Despite many claims to the contrary, the exact form of the worm thread is not essential, provided the relationship between the tool angle and the helix angle is within the bounds of good design. It is most essential that the form of the thread on the worm and the form of thread on the hob that is used to generate the mating worm gear are the same. If the form, size, and position of the finishing tool for the worm thread are specified, the hob maker can finish the thread of his hob blank in the same manner. Then his relieving tool can be shaped or adjusted to this correctly developed form so that reliable and consistent results can be obtained. Many seemingly obscure troubles in the production of worm gear drives can be traced back to the indefinite information appearing on the component drawing of the worm. No attempt is ever made to define the form of the teeth on the worm gear except by reference to the hob or to the mating worm.

A similar procedure is generally followed for the specification of the forms of any gear teeth. These are commonly defined in terms of the form of the basic rack which can be used to produce them. Similarly, the form of a lift cam is often specified by the position of the center of a roller follower of given diameter, or of the equivalcnt cutter which will be used to produce it. In fact, such a method should be followed in all cases where the formed surface is spiral or helical.

Changes to Adapt Part to Process

Some time ago, a short article written by a tool designer appeared in one of the mechanical publications. He commented on the difficulty of persuading the product designer to make alterations in his component drawings that would simplify the design of the tools, reduce their cost, and often reduce the cost of production of the part. He stated that after long experience and many futile pleas for mercy, he had been forced to the conclusion that the chief concern of the product designer was to devise such conditions, shapes, and arrangements that the component parts could not be machined by any known manufacturing process. Each new component was a challenge to the tool designer's ingenuity and ability. His only recourse was to meet this challenge and to design tools and adapt processes that would produce the results, even though this consumed additional time in the design, required more elaborate and expensive tools than would otherwise be

necessary, often required some experimental work before the tool designs could be completed, and generally resulted in a more costly operation in the shop throughout the life of the production of that component.

Such conditions are inexcusable, and are definite evidence that the whole problem of production design has received little or no attention. Before production has started, there should never be any objection to making changes in the component drawings that simplify any of the succeeding tasks, provided these changes do not impair the quality of the product. It is surprising how frequently these changes, often in the direction of simplicity, not only reduce costs but improve the quality of the product as well.

Surface Finish

At present, one of the most unsatisfactory elements of the language of drawings is the matter of designating the exact type of surface finish required. This problem is fundamental. Our knowledge of different types of surfaces, with their most effective uses and limitations, is so slight that usually it is left to the shop to solve the problem by bitter experience. At present, the best that we can do is to specify the process, such as finish turn, finish grind, scrape, or lap. But there are all degrees of smoothness and finish obtained by each of these processes. Where bending fatigue is a factor, we know that the direction of the scratches left by the finishing process, as well as their depth and shape, has a pronounced influence. We may assume that we cannot have a surface too smooth, only to find out that in one case an optically smooth surface is of definite advantage whereas in another seemingly similar case, beyond a certain point, greater smoothness is actually detrimental.

Much thought and experimental work is now being devoted to this subject of surface finish. One of the first essentials to evaluating experimental results and to definite specifications is a satisfactory method of measuring this surface finish. No specification is precise and definite until an adequate means of checking or measuring is available. Some very fine instruments for measuring the profiles of surfaces, such as the number and some measure of the depth of the scratches, are now on the market; but as yet we have not sufficient experimental and service data to judge the real effectiveness of the particular characteristics of the surface finish that these different instruments actually measure. As we are able to gather this information, possibly as it applies to some particular surface on some specific part, we should include it as part of the specifications on the component drawing,

either directly or by reference to some standard specification of surface finish. In time we hope to have such information. When that time comes, and as it approaches, we should take steps to compile definite specifications so that this notation on the drawing will need to be only a reference to this standard specification. In the meantime we must do the best we can, and should record all usable information on our component drawings, or set up some tentative specifications of surface finish.

Materials and Heat Treatment

The composition and the physical condition of the materials of which the component parts are to be made should appear on the component drawings, either by reference to standard specifications or as a complete specification for the particular part. Suitable standard specifications are usually available. Even here, however, we may need to make note on the component drawing of some particular feature, such as the range of hardness and depth of case for case-hardened parts. Sometimes only part of the surface is to be hardened, then this information must be indicated clearly. The introduction of the flame-hardening process may require some notation as to the extent of the surface to be hardened as well as the depth of hardening.

Frequently when hardened steel parts are involved, it is essential that the structure of the steel, before machining is started, be kept to some uniform condition so that the distortions in hardening will be similar on all parts. This may require the segregation of the bars or forgings according to the particular heats of the steel as it was first made at the steel mill. When this is necessary, the instructions must appear either on the component drawing or in a special specification for the part in question. In essence, all pertinent information available should be recorded and kept up to date in a form that will be on hand when needed.

The information about the materials, given or indicated on the component drawings, is generally the source of information for the purchasing department when placing orders for the material required to meet a given production order.

Miscellaneous Information

All pertinent information available which will assist the shop to do its part of the work intelligently and effectively should be recorded either on the component drawings or on the operation lists as they are developed, or in special specifications for the part in question. For example, on some sheet-metal parts it is essential that the burr side

of the punching be on a particular side of the part. The burr side should then be indicated on the component drawing. Again, on similar parts, the direction of the grain or fiber structure may be important and should be noted on the component drawing.

In the making of small parts, after a certain operation the parts are often placed or stacked in special carrying and processing racks, and remain there through several further processes without any individual handling of these parts. The specification of the use of these racks belongs on the operation list, as well as the information about any safety precautions or equipment that may be required on hazardous operations. Even so, the production design engineer may foresee many of these needs, and he should take steps, possibly by means of a memorandum, to call these conditions to the attention of the process engineer who makes the operation layout.

When this production design is being developed, the solution chosen may be based on the use of a particular type of holding fixture or cutting tool, or upon some simple modification of some standard process. The production design engineer should then make some note of this, perhaps in the form of sketches, and should see that the information reaches the hands of the persons working on operation layouts and the tool designs.

Revisions of Component Drawings

If we are to exploit the information we gain from our experience and mistakes in starting and continuing the production of a product, we should establish a definite routine for the revision of our component drawings so that this information would be recorded and used. Any corrections or revisions should be made without question, once their need or value becomes apparent. Of course some check must be made of the influence of such changes on the existing equipment: revisions of drawings which also entail expensive changes in the existing production tools must justify their expense. A change will often be proposed after production is under way which should have been adopted, if known, before the tools were made. But if the tools are made and this alteration involves more expense in changing the tools than the improvement is worth, it should not be made. Nevertheless it might be something that could be used to advantage on some new product in the future. Thought should be given to devising a plan of filing these unused suggestions because of their probable future value.

All mistakes are inexcusable, but we all make them. All mistakes are not total losses. We learn more from our mistakes than from our successes, but to make the same mistakes over and over again is un-

forgivable; it is evidence that we have not learned or profited from them. It has often happened that the results of a mistake have uncovered information urgently needed, information that would cost more to obtain from definite experiments than the cost of correcting the mistake. But, to attain this end, someone must be there who can recognize the import of the results. It may be a good plan to condone mistakes when the person responsible is able to report some salvage, or even profit, from the information so disclosed; and to condemn them only when the person responsible makes no attempt to profit by the experience.

A direct and open channel should always exist between the production design department and the production floor. If the component drawings prove incomplete or so misleading as to cause trouble, no matter how trivial that trouble may be, the attempt should be made to correct or reword or complete them so as to avoid similar troubles in the future. The drawings for our existing products are generally used as a model for the drawings of a new product, hence such information and improvements in the language of our drawings will serve a double purpose: the improvement of our present practice and the application of our experience to all our future products.

Even with the benefit of all our past experience, and all the care we can give to make these component drawings complete, consistent, and intelligible, the first issue can be nothing more than our first guess. An old mentor of mine once told me that one outstanding characteristic of a good designer was that he had no mercy on his eraser. This holds true particularly for the one who works on the production design. The process of erasing will continue as long as the product is manufactured.

In some factories there is a feeling that after the first issue of blueprints has been distributed, everything on them has acquired a status that approaches the sacrosanct. To suggest a change is considered a criticism of the work and the judgment of the designer. This is an unfortunate attitude, and it stifles cooperation. The attitude should be that the drawings represent the best that can be done with the limited information in hand; suggestions for improvements and notice of need of corrections should be welcomed, because this will add to the information and help to make the next job better.

CHAPTER III

PLANNING THE EQUIPMENT

When the first draft of the production design is complete, plans must be made for designing, making, and installing all the special productive equipment that may be necessary to produce this design. To make the proper allotments and to set up specific budgets of time and money, the general management must know the probable cost of the equipment, the length of time required to make it, and the factory cost of the product. To collect this information and to make more definite plans for all the succeeding work as an increasingly large number of persons are brought into it, we must start with an estimate. The original estimate may be made in considerable detail, and may specify the type and amount of manufacturing equipment needed, the cost and the time required to obtain the special tools, and the factory cost of the product itself. If it is compiled in this way, the estimate sets up tentative outlines and schedules for the greater part of the remaining work of preparation for manufacture, and, as the actual work progresses, these tentative outlines are modified as found necessary.

On the other hand, the original estimate may concentrate on the probable cost of manufacture of the new product alone; then the other schedules must be made later as they are needed. Even here, some tentative list of manufacturing operations is necessary, however.

The work which is preliminary to starting a new product, consists of the experimental or functional design and the production design, and is done by individuals or small groups working closely together. When this work is done—at least to the point where definite plans for production are justified—many more people can work together effectively than before. For example, the work on each component part of the product can be assigned to a different person or group who will make the estimate and draw up the operation list. After the operation lists are ready, the tool design and other planning for each individual part and each individual operation on that part can be assigned to a different person, when time is essential and the planning force is large enough. Here the production design is the common bond that keeps the planning of many individuals to a definite, consistent course.

Estimating

Before starting the production of a new commodity, an estimate must be made of the probable cost of manufacture. Estimates are also required to anticipate the amount and types of manufacturing equipment needed to meet a definite production schedule. They are also needed when any change in production on an existing product is contemplated in order to forecast the effect of the change on the cost of production. In fact, all new production schedules depend on some form of estimate.

Estimating is usually done by specialists thoroughly familiar with the particular plant and personnel. They may be assisted by process engineers, as well as by many kinds of statistics developed from the records of past performances. Frequently, they may consult with foremen or other persons who will be responsible for the actual production. Even if the official estimating is done by specialists, every process engineer should have some facility along these lines. He will often suggest changes which he has good reason to believe will reduce the costs of production. After the suggestions have been considered, if they seem to have merit, they are referred to the estimating department for study. An estimate may show an increased cost instead of a decreased one, and, if the person who made the suggestion knows nothing of estimating, he is helpless. If, however, he does know something of the process, he can interview the estimator on the method of estimating. Often it becomes evident that the estimator has not understood or has not grasped the full significance of the suggestion. After the discussion has clarified the suggestion, a revised estimate is made. The result in this revised estimate is often quite different from that in the first.

An estimate is only a guess, but it should be based on all known and measurable factors as well as on past performances. In general, the quantity to be produced has a pronounced influence upon the cost of production—the greater the quantity, the lower the unit cost will be. This is the result of many factors. For one thing, the greater the quantity, the more elaborate and complete will be the manufacturing equipment needed. This means more expense for equipment, but the greater quantity can absorb the higher preparation costs. With more effective equipment, the direct labor costs are reduced. Also, with constant repetition of a given task, the workman acquires a skill, technique, and speed that come only from long acquaintance and constant practice. On the other hand, the greater the rate of production, the more nearly perfect the production design must be. Incompleteness and

mistakes become increasingly costly as the rate of production increases.

Yet whether the quantities are large or small, an estimate should be available before any further actual steps toward production are taken. Although the principles involved may be the same, the actual problem of estimating for single units or small quantities is quite different from the problem of estimating for large quantities, but even in a large plant where great quantities are the rule, estimates for single units and small quantities are required when planning for the tools and the other special equipment. In general, accurate estimates for small quantities are much more difficult to make than accurate estimates for large quantities. Fortunately, however, estimates for small quantities, such as the cost of a special tool, usually involve relatively small sums of money so that their accuracy is not so vital as the accuracy of estimates for large quantities. The engineer's estimate is made in units of time and materials. These values may be converted into dollars and cents by using the prevailing labor and overhead rates.

Almost every estimator has his own methods for solving his own problems, yet all these different methods will have many things in common. Thus there are four time factors involved in any specific production task which must be accounted for in some manner. These are as follows:

(*a*) The time needed to set up the equipment and to get started on each new task. (Set-up time.)

(*b*) The time consumed by the travel of the cutting tool over the surface to be machined. (Machine time.)

(*c*) The time consumed by the operator in locating, clamping, removing work, measuring, etc. (Man time.)

(*d*) The time lost from actual production because of sharpening tools, waiting for material, attention to personal needs, etc. (Maintenance time.)

Of all these time factors, only the second, machine time, can be calculated definitely. The values for all the others are reached by some reference to previous performances which may range from detailed statistical values derived from time and motion studies to general average or percentage values for the different kinds of operations.

In general, the methods of estimating may be divided into two main classifications: first, direct comparison with the time required to machine some similar part; and second, a detailed estimate of the time required for each element of the job, in which case the answer will be the sum of the calculated values and those selected from the statistical values. At times both types may be used, one to check the other.

Before proceeding further, it would be well to classify the production facilities into their three general types. These are as follows:

(*a*) Manually operated. This type includes all bench work, and most of the general tool room and machine shop equipment—even that with power feeds—where the operation requires the constant attention of the mechanic to control the action of the machine.

(*b*) Semi-automatic equipment. This includes all machines that operate through the cycle of the production of a single piece. The operator loads, unloads, and starts the machine for each successive cycle.

(*c*) Full-automatic equipment. In this equipment type are all machines that operate continuously through successive cycles. The material may be introduced as wire or bar stock, parts may be loaded from a magazine and unloaded, or the parts may be loaded and unloaded manually at a loading station while machining is proceeding at other stations on other parts.

Estimates for Small Lots

Practically all parts made singly or in small lots are handled on the first type of equipment, the manually operated. Here the only time factor that can be calculated is the machine time. If we establish or assume the feeds and speeds to be used and the number of cuts, we can readily calculate this time factor. Some plants have standard time allowances for the starting of a new job and the setting up of different kinds of machines. This takes care of the set-up time. We may also have some standard time allowances for the different parts of the man time and for maintenance time, or its equivalent. If we do not, we may determine some such usable values for our own purposes.

As a different and simpler method, we may determine from past performances some factor to apply to different types of operations, by which we multiply our calculated machine time. For example, on work produced on lathes, planers, shapers, boring mills, milling machines, and grinding machines, if the calculated machine time is multiplied by about four, we will generally come very close to the total time required for the production of a single piece of average accuracy. If the tolerances are small, more time will be spent in measuring the work, adjusting the machine, and more cuts may need to be taken than for less exacting work. More time, therefore, must be allowed for the task. For drilling, so much time is usually needed for laying out that a larger factor is necessary. In any event, a study of past performances will generally make it possible to establish some factor which will prove adequate for this type of estimating.

Bench work such as filing, scraping, hand reaming, and hand tapping may be classified, and standard time allowances established. Again, where a given type of special machine or fixture is to be made, the bench work may prove to average a given percentage of the total of the time required to do the machining, including set-up, machine, man, and maintenance time. In addition, the assembling time will often prove to be close to an average percentage of the time needed to make the parts. For a special machine, if the time used to make the parts amounts to, say, five thousand hours, the time required for fitting and assembly will often prove to be about the same amount. No claim is made that the definite figures given above are the correct ones for all plants. The point is that with study and experience, the estimator can arrive at suitable factors of this character, always to be employed with discretion, for use in any particular plant. Such data may have a further value. By checking these guesses against actual performances, particularly when the performance is better or worse than the estimate, conditions that can be improved will become apparent. With such improvements, the factors may be revised downward, and a material reduction of time and cost of tool work may be realized in the shop.

The foregoing relates to the actual time which will be charged against the job. Another question is that of the elapsed time between starting and finishing any specific order. A value for the elapsed time is essential when planning the start of new production. When emergency repairs are needed on equipment already in use, the minimum elapsed time is vital. This applies primarily to tool making. Both the elapsed time and the actual working time are affected materially by the type of organization of the tool room.

Roughly speaking, there are two types of organizations for a general machine shop or tool room. The first and earliest type employs general all-round mechanics and tool makers. The making of a specific part or a complete tool is assigned to one man, who may use any or all equipment, and who carries the specific job through to completion. The amount of machinery per workman and per unit of production is greater here than in the second type where specialists are employed. Even here some time is lost by the workman having to wait for his turn to use some piece of equipment. As a result, the actual working time for completing a given job or tool is greater here than in the second case. The elapsed time, however, from the start to the finish of the task is at a minimum.

The second type of organization employs specialists on each type of operation. This is quite similar to the conditions on the production floor. Each of several mechanics does his part in the making of a single

piece. The amount of equipment, number of men, and actual working time charged against a given job are at a minimum, hence the cost is less than in the first type. In order to keep the force busy, however, the work must be planned in advance and the next job must be waiting for each man before he has finished his current task. The work therefore waits for the man, and there is a wait for each operation on each piece, with the result that the elapsed time taken to complete any given job is much greater than in the first case.

Where work can be planned well in advance, and the necessary elapsed time can be provided for, the second method is the more economical, but even under the most favorable conditions emergencies arise: a tool may be broken or badly damaged by accident with no replacement tool at hand. Here the actual cost of the tool is secondary because of the expense of the delay in or interruption to the flow of production in the shop. The expense of an extra day's delay in production would pay for many tools at their normal price. If such emergency conditions are the rule, as in many small plants where the tool-making facilities are reduced to the minimum required for maintenance, the first type of organization for the tool room may ultimately prove to be the more effective. In larger plants, which have a large volume of routine maintenance that can be planned in advance, it is often necessary to have two tool rooms if there is an appreciable volume of emergency repairs. One is for the routine maintenance and is organized as a group of specialists. This will be the larger and regular tool room. The other will be a smaller emergency tool room organized as one of the first type.

In some places, as an expedient, there is only one tool room and it is organized as one of the second type. Emergency jobs are carried through it by special "chasers," and this work is carried from operation to operation by them. This emergency work is given precedence over the routine schedule. This, consequently, has a disturbing influence on the regular schedule, and the time charged to such emergency jobs does not represent the true cost of the work. It may be the best expedient when such emergencies are few. If they are many, the establishment of a separate emergency tool room is worth serious consideration.

Either the estimator or the person who makes up the final operation lists should indicate the elapsed time necessary to obtain new tools. This information is needed in preparing the definite schedules for the tool design, tool building, and the starting of production on the new or changed product. It is often possible to establish an average value for this elapsed time for the different types of equipment, values which

are based on past performances. In the absence of other information, the person making the definite schedules can use these average values.

Estimates for Production

A large part of the equipment used to machine the parts of the product is often of the semi-automatic or full-automatic type. Here the time required to go through the cycle of operations is determined by the speed of the machine, which is determined in advance. For continuous production, the set-up time is generally ignored, except when scheduling the start of production on a new part, and is used here only for the purpose of making the original estimate of the time when the work should be started. For parts which are made in lots, with frequent changes of set-up to produce different parts on the same machine, the set-up time must be considered in the cost estimates. For such use, an established average time is generally used. As for the full-automatic machine, the time per piece is controlled mechanically by the speed of the machine, and this speed is predetermined. Therefore these estimates are very accurate. True, after production is started, it may be found possible to increase the speed on some parts, or necessary to reduce it slightly on others; yet the total estimate will be very close to the actual performance.

For the semi-automatic equipment, if a standard design or practice has been followed for the operating characteristics of the fixtures, a similar degree of accuracy of estimates can be attained. The time per cycle of machine is controlled mechanically, the man time required for handling the work approaches an average value, so that in practically all aspects, the problem of estimating is substantially the same as that for the full-automatic machines.

The operating instructions issued by the manufacturers of this machinery usually give information and instructions so that the time per cycle of the machine can be determined for any selected speed, feed, and length of cut which is to be used. One such book of instructions for an automatic screw machine gives the following directions.

The steps followed are:

1. Decide on method of doing job, tools required and order of operations.
2. Determine spindle speed.
3. Figure throws of cam lobes and spindle revolutions required for cutting operations.
4. Overlap operations wherever possible.
5. Figure spindle revolutions required for idle movements.
6. Provide clearance space if necessary.
7. Find total estimated spindle revolutions required to finish a piece and

then select the actual revolutions available with regular change gears that come nearest to the estimated number.

8. Re-adjust the estimated spindle revolutions to total the actual number available on machine.

Estimates which involve the use of semi-automatic and full-automatic machines give the results to be expected if they are operated continuously with no stops for any purpose. There is always a certain amount of time lost from production, a time factor which we have called "maintenance time." This averages some percentage of the total time, and such values should be determined. It is well to do this both by analysis and by checking records of actual performance. All such items as time out for repairs, idle time because of sickness or absence of operators, time lost by set-up, production lost in training new operators, and average length of assignment of operators to particular types of equipment, as well as idle time due to lack of work or material, must be included. Studies of this kind show that on various types of equipment the actual productive time ranges from about sixty per cent to ninety per cent of the full working time available. These conditions must be considered in the estimates so that both the cost of production and the amount of equipment needed to meet a specified production schedule may be accurately determined.

Metal Working Processes and Equipment

Although many texts are available which cover in detail the subject of metal working processes, it is pertinent to include a brief summary of the more important processes from which the process engineer who makes up the final operation list makes his selection. Speaking generally, metal working processes may be divided into four main classes: first, hot working of metals; second, cold working of metals; third, shearing or punching of metals; and fourth, cutting or whittling of metals.

Hot Working of Metals

The hot working of metals consists of heating them until they are molten or plastic so that they can be poured or forced into the desired forms or shapes. In general, these processes are used for preliminary operations, the material being shaped so that it can be finished more conveniently by some other process. In some of these processes, however, the methods have been improved or refined to the extent that a finished product may be obtained.

It should be kept in mind that some of the raw material for one plant may be the finished product of another. For example, the product

of a foundry is castings. These castings, in turn, form part of the raw material for the machine shop. Yet sash weights, which are rough castings, are finished and ready for use when they come from the foundry.

There are many kinds of hot working processes. The more important of them are (*a*) casting, (*b*) forging, (*c*) hot rolling, (*d*) hot drawing, (*e*) extrusion, (*f*) welding. Each of these may be subdivided into several types. A brief and incomplete summary follows, starting with casting.

Casting of Metals

A casting is produced by pouring the molten metal into molds of the desired form and size where it is allowed to solidify. This process may be divided into three classes: first, casting in sand molds; second, casting in permanent molds; and third, die casting.

Casting in Sand Molds. Where any appreciable number of castings are required, and even for a single casting when the form is intricate, a pattern of wood, plaster of paris, or metal is made. The sand is pressed or tamped around this pattern, then the pattern is removed. Cores are often made in a somewhat similar manner in suitable core boxes to form the inside surfaces of a casting and for cast holes. These cores are placed in the mold, the several parts of the mold are assembled, then the molten metal is poured into it.

The product from sand molds usually varies so much in size and it has such rough surfaces that some further machining operations are usually required before it is in its finished state. Each sand mold is destroyed when the casting is removed, so that it is necessary to make a new mold for each individual casting.

Casting in Permanent Molds. For some parts of simple shape, in order to reduce the expense of molding, and also to improve the smoothness of the cast surfaces, permanent molds made of metal, usually cast iron, are frequently used. These metal molds are sometimes used with metal cores and sometimes with sand cores, depending upon the size and shape of the cored recess.

Cast pipe and other hollow cylindrical castings may be produced in revolving metal molds. Here no cores are needed because the centrifugal force acting on the molten metal holds it against the mold. In these castings, the heavier and sounder material is forced to the outside, while the lighter slag is kept to the inside. When a finished bore is required, this inferior metal is removed by the boring. This process is often called centrifugal casting.

Die Casting. Die casting is a further refinement of the process of

casting. Here both the molds and the cores are usually made of steel, and the resulting product requires little or no further machining. At the present time, the process of die casting is limited to the use of metals and alloys with low melting points—below 2000°F. as a maximum and below 1000°F. in the majority of cases—and it is also limited to the production of relatively small or light parts. The die-casting process is not yet a general machine shop practice, but it is used most in specialized plants that often make this type of work their entire business. The cost of the dies is high, but when very large quantities are needed, the over-all cost of the product will be low.

Forging

Forging consists of hammering or squeezing a hot plastic material into the form required. This process may be one of several types, such as hand forging, both manually and with a steam hammer, drop forging, and machine forging.

Hand Forging. Hand forging consists of striking the heated plastic metal with hammers of various sizes on an anvil, or hammering it between a swage and swage block inserted in the anvil. For very large forgings, a steam hammer with a variety of handling tackle may be used. The results in both methods are governed by the manual operation or control of the equipment.

Drop Forging. When large quantities of similar forgings are required, they are often made in hardened steel dies which are mounted in drop hammers. This process is known as drop forging. A set of several dies, which gradually shape the heated bar to the final form, is generally used.

Machine Forging. Special forging machines, some for upsetting, others for swaging, and some for both, are available in many sizes and types. Upsetting is the process of increasing the size or area of the section whereas swaging is the process of reducing the size or area of the section. These machines are widely used for the forging of blanks for bolts and for other small forgings.

Hot Rolling

Hot rolling consists of feeding the hot plastic metal between rolls where it is squeezed to form. Straight rolls are used to produce plates and strips and formed rolls are used to produce round rods and structural steel shapes. Occasionally a special varying form is developed into the periphery of the rolls which permits this hot rolling process to be used for the production of forgings of simple form.

Hot Drawing

The term "drawing" is used for two different processes which draw out the metal to form. One, which might be called cupping, consists of forcing material into a hole or die so that the plastic metal is displaced and forced to flow between the punch and the die, thus forming a cup or hollow cylinder with a bottom. The other process consists of pulling the metal, either in a solid bar or as a hollow tube, through a hole or die of the shape and size desired. The starting end will be swaged down so that it is small enough to go through the die and be attached to the pulling or drawing element. Hot drawing consists of heating materials to a more plastic condition, and of employing either of these two processes to shape them. The second process is quite commonly used in the production of tubes and pipes.

Extrusion

The extrusion of metal is another plastic flow process that is receiving an increasing amount of attention. In this process, the metal is forced by pressure through an opening of the required shape and size, sometimes over a mandrel to produce hollow forms. As an example, practically all the tubes used for glue, artists' paints, tooth paste, etc., are formed by extrusion. This process is used on the more plastic materials such as lead, tin, brass, aluminum, and Dowmetal. Many of the small-shaped forms used in the construction of automobile bodies are formed by extrusion.

Welding

Welding, a process used for the joining of materials, has many types. It is applied in many ways. This subject in itself is a large and interesting one. Welding is used both as an assembling method and also for purposes of repairs. Many parts, such as machine frames, gear blanks, brackets, and containers are built up of smaller pieces of plate metal and welded together.

The foregoing gives only a brief outline of some of the most important of the hot working processes. In general, the cost of such processing is low compared with the cost of cutting metal to size and form. As noted before, many of these processes are used for the preliminary operations. For one thing, many of them leave scale, or a rough surface even when the scale has been removed, as a direct result of the heating of the metal. Also, because of this heating, of variations in temperature and the corresponding differing amounts of thermal expansion, the variations in the size of the hot-finished product will be comparatively large.

We will next consider some of the more important of the cold working processes:

Cold Working of Metals

Many of the cold working processes are similar, almost identical, to the hot working processes. They are employed on materials which are plastic enough without heating to be forced to size or shape. In general, the surfaces of cold-worked materials are very much smoother than the corresponding surfaces of hot-worked metals, and the sizes can be controlled within quite close tolerances. Frequently, the smoothness of surface and accuracy of size produced by some of these cold working processes are much better than can be obtained by many of the cutting processes, and it is possible to employ many of these processes to produce finished surfaces that need no further machining. These processes are also very economical and compare favorably in cost to many of the similar hot working processes.

The cold working of the metal changes the hardness and some of the other physical characteristics of the material. For some metals, it is necessary to anneal the material between successive cold working operations, otherwise the metal would become too hard and too brittle, and would break or crack in the succeeding cold working process.

The more important cold working processes are (*a*) cold rolling, (*b*) drawing, (*c*) spinning, (*d*) coining, (*e*) embossing, (*f*) cold forging, (*g*) bending.

Cold Rolling

This process is very similar to hot rolling, and is used to produce flat and round shapes, as well as various sections of simple form. Sheets and strips of brass and steel are classified as hard, half hard, drawing stock, etc., with many intermediate grades. These differences in hardness are controlled primarily by the amount of reduction of area after the last annealing. In other words, they represent different degrees of cold working.

Drawing

Here, as with hot drawing, the term is used for two different processes, the cupping and the pulling of metal through a die of the desired shape and size. Deep drawing consists of several successive operations of cupping, with annealing between operations when required. The art of drawing sheet metal is a very comprehensive one, and many texts are available describing its many phases and applications.

Spinning

The process of spinning is somewhat akin to drawing, or cupping, and consists of revolving a piece of sheet metal or tubing and forcing the metal to flow by the use of a spinning tool until it fits a form which is also carried on the revolving head. At times the form and metal are stationary while the spinning tool revolves. The control of the plastic flow of the metal is better in spinning than it is in drawing; therefore some conditions which cannot be met by drawing can sometimes be met by spinning. This process was almost abandoned for about a generation, except for its use in the making of band instruments, but now it is finding more and more applications.

Coining

The process of coining was originally used for making coins and is now applied to many other products. It consists of hammering or squeezing the metal slug between two dies, shaped as required, until the metal flows to the required extent. In many respects, it is a form of cold forging. Hand hammers and drop hammers were employed at first, but now most of such work is done in a toggle, or coining press which has been developed for this purpose. In the majority of cases, a single application of pressure is used. There are conditions, however, where several repeated applications of pressure are necessary. The steel type for a typewriter, for example, is formed in a special kneading machine which applies the pressure several times as the metal is kneaded into the die or matrix. Another interesting application of the process of coining is its use for sizing and finishing the surfaces of bosses on steel forgings as a substitute for milling, a more expensive and less accurate process than coining. Knurling is another type of coining and is done on screw machines.

Embossing

Embossing is essentially a shallow drawing operation. It is used to make raised letters and patterns on sheet metal. At times mating dies are used but at others only one die is used while the metal is forced into it hydraulically or by an elastic cushion made of rubber. Where a cylindrical form is forced out to fit a die of desired form by means of a rubber insert which is deformed by the pressure of a punch, bulging dies are frequently used to produce shaped containers of many types. This might be considered as a form of drawing or as an application of embossing. It is one of the many processes for forming parts from sheet metal.

Cold Forging

The process of cold forging is similar in many respects to the process of forging hot metals. The same, or very similar types of power equipment are used for both processes. At times, castings of the more plastic metals are cold forged to obtain smoother surfaces and more accurate dimensions than can be obtained from the casting process alone.

Bending

The process of bending is employed for many purposes. Pipes are bent by a set of bending rolls and also by forcing them through curved dies. The winding of wire springs is another application of bending. Plates for boilers and other curved vessels may be formed by a set of bending rolls, whereas conversely, coiled rods and wire are often straightened by a set of rolls suitably adjusted.

The bending of sheet metal may be accomplished by the use of dies mounted in power presses. This is another one of the many sheet-metal processes available for the forming of sheet-metal parts.

Shearing or Punching of Metals

Many of the shearing processes, particularly those used for sheet metal, are performed on the same types of power presses as those used for performing some of the cold working processes. These processes are part of the extensive art of the forming and shaping of sheet metal. In these shearing processes, part of the metal is punched or sheared out of the surrounding metal by the shearing edges of the punch and die. Punching, or piercing, is a term applied to the punching of a hole. Blanking is a term used for the process of shearing the outline of the part or blank. Punches and dies may be made to punch holes alone, to blank alone, to punch and blank together, or to bend part of the blank in combination with any other series of operations. In fact, the many combinations of operations that may be performed in one action of the power press are almost unlimited.

Special machines which can perform a series of operations at several successive positions are known as eyelet machines, probably because they were first developed for making metal eyelets. Although the first tool cost may be high, all these sheet-metal processes are among the least expensive, and they are well adapted to the needs of mass production.

Heavier metal-shearing machines are used to cut off bars of stock, cut up scrap material, trim the edges of large sheets of sheet metal, etc. For manual operation, we have several types of shears for tinsmiths, whereas we have bolt cutters for heavier stock.

Cutting or Whittling of Metal

There are many types of processes for removing metal in chips. These processes are generally used for the purpose of obtaining a smooth finished surface which will be positioned within fairly close limits. If we classify them according to the type or size of chips produced, we have three main classes: (*a*) continuous chips, (*b*) small individual chips, (*c*) fine and pulverized chips.

Continuous Chips

Most of the general purpose machine tools which remove metal in a substantially continuous chip, except as it breaks of itself or because of a chip-breaking device, can use the same cutting tool, or same type of cutting tool. These processes include the following, which should require no further description: (*a*) turning, (*b*) boring, (*c*) planing, (*d*) shaping.

Many types of special production machines, both semi-automatic and full-automatic, have been designed for specialized purposes. Among them are automatic screw machines, chucking machines, turret lathes, automatic lathes, and multiple-spindle boring machines, on which the principal operations performed are those of turning and boring. There is also the gear shaper which generates the gear tooth forms by means of the shaping process.

All these processes leave on the product a surface which is quite similar in all essential respects. To a large extent, they are all one process, which is applied in a different way in order to produce a different form of surface.

Small Individual Chips

There is an almost infinite number of different processes, or different applications and combinations of processes, that finish the surfaces of metal parts by removing the metal in small individual chips. They can be classified, however, into a few general classes. Practically all the other specialized processes are primarily a modification of one or more of these general classes which have been combined or used for a particular purpose. These general processes are as follows: (*a*) drilling, (*b*) counterboring, (*c*) filing, (*d*) milling, (*e*) broaching, (*f*) sawing.

Drilling is a distinctive type of operation, but all the others have much in common. Milling, for example, was first developed as a power-driven rotary file. A broach is, in essence, a coarse-toothed formed file; and sawing with a slitting saw is also a form of rotary filing. The broach will give a smoother surface than a milling cutter. A surface

broaching process has been recently developed which is being used in many places as a substitute for milling because it gives this smoother finish and also because it is a less expensive process, although the first cost of a broach may be much greater than the first cost of a milling cutter.

Fine and Pulverized Chips

There is a great variety of processes which finish the surface of metal parts by removing very small, and sometimes microscopic chips. Among them are the following: (*a*) reaming, (*b*) scraping, (*c*) grinding, (*d*) lapping, (*e*) stoning or honing, (*f*) polishing with emery cloth, (*g*) polishing with rag wheel and abrasive.

Reaming and scraping are similar finishing processes. Reaming is used to scrape off small amounts of material to smooth the surface and correct the size of drilled or bored holes. Scraping is a hand operation which is employed to smooth the surface or correct the size and form of flat surfaces and of some of the larger holes which are used as bearing surfaces. A special application of this process, applied mechanically, is found in the shaving machines used to finish the surfaces of gears. This shaving process might be classified as about half-way between filing and scraping.

A study of the cutting action and chip formation of abrasive grinding wheels shows that in many essentials it is the same as milling. This process was originally used only for finishing operations. Today, it has been developed to the point where it can often be used effectively for roughing operations also.

Lapping is an abrasive finishing operation. It may be done manually or on any of several types of lapping machines which have been developed for particular purposes. A lapping compound, composed of a powdered abrasive and a liquid, is fed between a softer lap and the harder surface of the part that is to be finished. The common notion is that the abrasive is forced or charged into the surface of the softer lap, where it is held while its sharp projecting edges remove microscopic chips from the product. Actually the abrasive rolls and slides between the two surfaces, and removes material from both surfaces, but removes much more from the harder surface than from the soft one. When no fresh lapping compound is introduced between the surfaces, the rate of cutting decreases quite rapidly, and soon the cutting will almost cease. When this process of lapping is carried to the extreme, with very fine abrasive, an almost optically smooth surface may be obtained. In fact, optical surfaces on glass are obtained by the use of this process. Generally, however, lapping is one of the most expensive processes. This is not true when large quantities of similar

parts are lapped on some of the special automatic lapping machines now available for specialized types or shapes of surfaces.

Stoning or honing may be done manually or on special machines. This process is used primarily for improving the smoothness of the surface finish.

Polishing with emery cloth may be done by hand or by the use of a disk of emery cloth mounted on a rotating metal disk. To some extent, it is a variant of the grinding process.

Polishing with a rag wheel and abrasive is generally a cleaning process, or one used to improve the smoothness and polish the surface. The use of a rag wheel permits the polishing of irregular forms and it is the method used to polish a part after a plating operation.

All these processes of cutting metal are quite expensive as compared with the cost of forming and shaping the metal by the other types of processes. Many valuable process developments have consisted of improving or adapting some of these cheaper processes to perform operations—often attaining much better results in finish and accuracy—that had formerly required the use of the more expensive cutting operations. For example, the development of thread rolling was, in effect, a special application of coining to the forming of screw threads, as a substitute for chasing the threads on a lathe or cutting them with a die. This thread rolling process is essentially a mass-production method.

In addition to these processes for the forming and shaping of metals, there are many more which are used for heat treating, annealing, plating, polishing, cleaning, etc. General purpose equipment is used for these processes and only very rarely is it necessary to provide special equipment here for the processing of specific component parts. When this is necessary, however, the plans for the preparation of production must include these items.

Many times the person who makes the operation lists must choose between different processes for use in the particular instance. This choice will be governed by the type of equipment available, the character of the surface finish obtained, and by the cost of production. Sometimes a cheaper process, which does not give the type of surface finish required, followed by another finishing or polishing operation, will be chosen in place of a more expensive single process that will give an adequate surface finish.

Machine Tool Equipment

Machine tool equipment may be roughly divided into two general classes: first, general purpose or universal machines; and second, single

purpose machines. In general, the universal machines are used for small quantity production whereas the single purpose and special machines are used for mass production.

The uses to which machine tools are put in various plants can be roughly divided into three classes, each of which makes somewhat different demands upon the equipment. The first of these uses is found in plants engaged in the manufacture of a variety of products in which duplication occurs to a very slight extent. This class also includes the maintenance and tool-making departments of the production plant and the small-job shop. This class of use requires universal machine tools of the widest possible range of usefulness, size, and type.

The second class of use is found in shops devoted to a fairly large production of a commodity that is subject to frequent changes of design, fluctuations in demand, or other conditions that make it impractical to assume that the manufacturing conditions and details will be fixed for any long period. The demands on the machine tools in this class of service are not nearly so varied as the demands in the previous class, although the equipment must still have a large degree of flexibility. The machine tool equipment in such a plant consists largely of standard machines provided with special fixtures. These standard or general purpose machines are supplemented by a few single purpose machines to take care of certain special operations.

The third class of use is found in plants engaged in the large and intensive production of a standardized product that is subject to very little change in design over appreciable periods of time. The plant must also be one whose standards of quality and whose production methods to maintain these standards have been definitely established. In plants of this class will be found many machines of special design, often full-automatic, which are capable of giving a large and continuous rate of production. The machines for this type of service are often selected and arranged so that one operator can take care of several machines with facility. At times the machines in a production line have almost lost their identity as individual machines, and have become, through the use of conveyors and automatic feeding devices, an integral part of a production unit that takes raw material at one end and turns out a finished component part at the other end.

Single Purpose and Special Machines

Single purpose machines are usually either full-automatic or semi-automatic. When full-automatic machines are used, one operator usually attends to a battery of several machines. With semi-automatic machines, one operator may be required for each machine, or when

the machining time is sufficient, one operator may handle a group of such machines. In general, the use of automatic machines greatly reduces the number of direct labor hours needed to produce a given component. Exceptions to this are occasionally met, particularly where the degree of accuracy required is exacting. It follows then that the use of automatic machines generally becomes more desirable and often necessary when labor is scarce or its cost is high.

It is possible to build a machine to perform any repetitive operation. Furthermore, such operations can often be performed mechanically with greater accuracy than by hand. However, it is not always simpler to do it mechanically. Yet, if extremely large quantities are required, sooner or later suitable methods will be devised to produce them mechanically.

When selecting automatic machinery to produce any given part, one of two courses is open. First, a special machine may be developed to produce only one part. Second, a more general purpose machine may be selected or developed which will not only produce the given part, but can also be adapted to make other similar parts.

When continuous production of one specific part is involved, a machine of the first type, that is, designed to produce only one thing, proves to be the most effective because it has only the adjustments and movements necessary for that job. Very often the quantities needed are not large enough to require continuous production. For this, the selection of the more general purpose type of machine that can be readjusted to produce other similar parts is the logical choice. Very good examples of this type are the well-known automatic screw machines.

The need of automatic machinery generally implies mass production of greater or less extent. In order to manufacture on such a basis successfully, many precautions must be taken which are not so necessary when smaller numbers of parts are produced. Where small quantities are involved, if some parts should be accidentally made larger or smaller than standard, it is a relatively easy matter to make a corresponding change in the size of their mating parts and thus salvage the off-standard components. Such a course is out of the question with mass production. In the first place, the quantities are so large that plans must be made and production started well in advance of their actual need at assembly. Any attempt to control this production by other than large lots would prove very difficult and expensive. In addition, even if a suitable control could be developed, the change in set-up required on the mating parts in order to salvage the first parts

would usually prove to be too expensive because of the interruption to the flow of regular production and of all the attending confusion.

In order to employ mass-production methods successfully, it is necessary to start with the design of the commodity to be produced, and adapt this design to suit this method of manufacture.

It should be obvious that mass production also involves rigid adherence to specified limits of size. These limits may be wide or close, depending upon the nature and design of the commodity. The wider these limits, the greater the possibilities of economical production. But wide or close, once these limits have been definitely set up and proved, they must be maintained.

The accuracy to which we can work depends upon the accuracy with which we can measure. The mere removal of material from a part in course of manufacture is seldom difficult. The critical point is knowing when to stop.

When parts of prescribed accuracy are required, however, the provision of suitable means of measuring is not alone sufficient to insure the results. The machines and tools employed to shape the raw material must be of suitable type and controllable within the required degree of accuracy.

It is plain, then, that if we are to produce parts of prescribed accuracy, we must choose a suitable method of machining them as well as having proper measuring equipment. In addition, the equipment on which the parts are made and the tools used to shape them must be sufficiently rugged and accurate. Yet although all these other factors must be met, the fact remains that the accuracy to which we can work depends upon the accuracy with which we can measure, because to make and maintain the productive equipment to the required degree of accuracy, we must be able to detect both the nature and the amount of the errors before we can correct them. When cause and effect are definitely established, the answer to any problem is in sight. It is significant that the most perplexing problems of manufacture persist because of the absence of suitable methods of measurement to determine the character and amount of the errors.

A distinction must be made between dimensions of size and dimensions of position because the factors governing both their measurements and their production vary considerably. A dimension of size is one that defines a length, thickness, or diameter. A dimension of position is one that defines the relationship of different surfaces to each other such as the location of holes, alignment or concentricity of different shoulders on a shaft, and parallelism.

In order to obtain the maximum accuracy of size, only a single

surface or a single dimension can be controlled by any one tool or other element of the machine. Take, for example, the cutting of a screw thread. If a die is used, the three main elements, the thread form, the lead, and the diameter, are controlled by one tool. Adjustment for diameter is possible, but the form and the lead are fixed. These fixed elements are as they exist on the die. Variations are introduced here when the die is hardened. When one die replaces another, these variations are different. When no high degree of accuracy is required, the use of dies is economical and satisfactory. As the requirements become more severe, the use of dies becomes more and more troublesome, until a point is reached where these tools cannot produce threads of the necessary accuracy. When the requirements are severe, this method of making screw threads is out of the question. Then the thread may be cut on a thread-milling machine or may be finished on a thread-grinding machine. Here the form alone is carried on the cutting tool and can be controlled to a high degree of accuracy. The diameter is controlled by the radial setting of the tool which can be readily and accurately adjusted and readjusted. The lead is controlled by the lead screw of the machine which can be made to any reasonable degree of accuracy.

Other types of composite surfaces present the same problem. If two steps are milled simultaneously on a piece, any variations in the relative diameters of the two milling cutters will introduce an additional element of error.

In order to get the maximum accuracy of position, on the other hand, the co-related surfaces should be machined at the same setting of the work if possible. A change in set-up here will introduce an additional factor of error in position.

The choice between full-automatic machines and semi-automatic ones is controlled by many factors. A full-automatic machine is not necessarily faster than a semi-automatic one. In fact, automatic machines are not always faster than manually operated ones, particularly when the requirements of accuracy are exacting. The two following examples bear directly upon these points.

Automatic machines are used extensively in the production of shot-shells and cartridges for small arms. One factory engaged in the production of shot-shells had to meet a fluctuating demand for such a wide variety that they could not be made in advance and stocked. In the summer, the production fell as low as one hundred thousand shot-shells a day, whereas in the autumn it rose rapidly to a peak of about two million a day. This peak production would continue for three or four months, and then decline to the low point again. Most of the

manufacturing operations had been performed on semi-automatic machines. The fluctuating demand for the product caused a corresponding variation in the number of machine operators.

Considerable difficulty was experienced in training new operators quickly to meet the rapidly growing rate of production in the fall, so it was decided to change these machines into full-automatic ones: first, to reduce the amount of training for the operators, and second, to reduce the number of operators required. The semi-automatic machines required an operator on each machine, whereas a single operator could tend from six to twelve of the full-automatic ones. The change was made, but the production of each full-automatic machine proved to be only about eighty per cent of that previously obtained from the same machines operated as semi-automatic ones. Nevertheless the change was well worth while because the use of the full-automatic machines enabled the plant to handle the fluctuating rate of production with much less expense and difficulty.

The other example gives an interesting comparison between the performance of some semi-automatic, multiple operation machines and that of some single operation, hand-operated machines. There has been a marked tendency during the past few years towards the design of automatic machines that will manufacture a given part in one or two operations. For the majority of metal parts where a high order of accuracy is not demanded, such equipment has proved to be successful and economical, but for parts with exacting requirements, where the cutting tools require constant attention for any reason, such machines are not always suitable because of the time lost from production while the tools are being tended. When the machine is running, the rate of production is high; but when one tool is being sharpened or readjusted, all the other tools are idle also. The more tools that require attention, the more often the machine must be stopped to attend to them.

An interesting example along these lines occurred in the machining of some cold-forged aluminum castings which required a high order of accuracy as well as a very smooth finish. Semi-automatic chucking machines were first used to make all the turning cuts in two operations. Much trouble was experienced in keeping the tools cleaned, sharpened, and adjusted. As a result, the actual production was only about one-half the amount that had been expected, and the deliveries on the contract were delayed.

In order to boost production, a line of small bench lathes which were on hand were fitted up to supplement the production from the semi-automatic machines. Each bench lathe was set up to take a single

cut. The machines were arranged close together along a bench so that the operators passed the work along from one to another as they finished their individual operations. This was accomplished by placing work trays on stands between the operators, so that the finished work tray for the first operator became the supply tray for the next operator. After this secondary production line had been in operation for several weeks, a check was made of the performance and cost of the two methods. This survey showed that the parts produced on the bench lathes were not only more accurate but also less expensive than those produced on the semi-automatic machines. As a result, the use of the semi-automatic machines was abandoned for this work.

At present the limitations of the multiple operation machines when applied to exacting work are better appreciated, and more attention is being given to the single purpose, single operation automatic machines which are necessary to meet the needs of rapid production of very accurate parts. As noted before, for the machining of the large majority of metal parts whose requirements are not exacting, the multiple operation machines prove very successful. When these single operation machines are full-automatic, with magazine feed, the labor cost of production on such equipment is no greater than on the multiple operation machines, the cutting tools are often simpler and cheaper, the rate of production is as large, the machines are often more adaptable to a wider range of work, and the possible accuracy of size and smoothness of finish is often greater than on multiple operation machines.

Operation Lists

The original operation list for any component part should show the sequence of the operations on that part, the nature of the operation, the type of machine tool or other basic equipment required, the type of work-holding device to be built, the cutting tools and the gages needed. It should also give the estimated rate of production so that the amount of equipment needed to meet any specific production schedule can be determined readily.

In preparing these operation lists, a selection must be made from the processes and types of equipment available, taking into account the accuracy required and attainable, the character of the surface finish needed, and the cost of the special equipment that will be required to adapt the selected equipment to the work in hand. Here, one may see ways to modify the design of the component to facilitate its manufacture, minor changes which may have escaped the attention of the production design group. Such details should be called to

the attention of this design group and the changes should be made if they do not affect the functioning of the product. In fact, many items of production design may be here worked out to advantage.

A separate operation list is required for each component part. Bench operations such as filing and inspection should be included. In effect, these operation lists are the assembly drawings from which are obtained the detailed information needed to guide the tool design and the tool making, the purchase of new equipment when needed, and the factory layout for the series of operations when such are necessary. As definite machines may be assigned, and as definite numbers or symbols may be given to the special equipment, tools, and gages, a revised operation list may be made in greatly condensed form, at least, as regards size of paper, where these specific numbers and symbols are used in place of the general descriptions. Such condensed lists often form a part of the specifications for the particular component part, and copies are filed in the offices of all production departments which do any part of the manufacturing. This is especially necessary where a plant makes a wide variety of products in separate lots and the equipment is set up for the production of one lot, and then the special equipment is removed and stored at the end of the job until it is needed for use, some time later, to manufacture another lot.

These operation lists will need revision as time goes on; the sequence of operations may be changed; some of the original operations may be subdivided, and some of them may be combined; and new and improved processes may be introduced which may require some modification of the product design. These lists should be kept up to date, even though this may require a periodical survey of the actual procedure on the production floor.

Special Factory Layouts

When the equipment for a particular component part is to be arranged in the order of its use for machining that part, it is necessary to make a factory layout to agree with the operation list and one which will fit into the available space in the factory. When many of these layouts must be made, it is a common practice to provide templates, made to the proper scale, for each type of equipment, and to place them on a drawing of the floor plan of the building, moving them around until they are arranged in the most favorable position that can be arranged.

Where heavy equipment is involved, these layouts must also include detailed plans for the foundations and the location of any foundation bolts required.

When special materials-handling equipment is necessary, the plans for this equipment are based upon the factory layout. If new lines for electric power, steam, compressed air, etc. are needed, the detailed requirements for them are also based upon these factory layouts. Here is where general standards for the installation of these accessory services will prove to be of great help.

Time Schedules for Tool Design, Tool Making, and Set-Up

Once the operation lists have been made, a greatly increased number of individuals can work simultaneously and effectively on all the many tasks involved in planning and making the special equipment that is required before the production of a new commodity can be started. To make most effective use of their time so that the new equipment will be ready when it is needed, some schedule must be set up. This schedule should show not only the order in which the individual tasks should be taken up, but also the definite dates on, or before which, each task must be started and finished. Furthermore, the actual progress of the work should be constantly checked against these detailed schedules. If the work is falling behind, either additional help must be supplied or some overtime work may be necessary.

For making such schedules, some data about the elapsed time required for each task must be at hand. Much of it may be statistical; some may require special estimates. At all events, such information is vitally needed. Having this, we can start from the time that the manufacture of a specific component part must be completed. By using the time required to set up the last operation on this part, we can work back through the elapsed time required to make or to procure the equipment for this operation and establish the date when the special equipment should be ordered. Again working back through the elapsed time that it will take to design this special equipment, we can determine the time when the design should be started.

The preceding operation must be set up and operating before we can complete the set-up on the last operation. Thus, if it takes about half a day to get a production operation started, the next-to-the-last operation on a given component part must be set up one-half day before the last operation can be started. If we work back as before, we can establish the dates when the tool making and the tool designing must be started and finished for this operation. This will be continued until schedules have been determined for each operation on every part. When sub-assembly operations are required, we must start with the last operation for the sub-assembly and work back to the last operation on each component part involved in this sub-assembly.

From such schedules of all the component parts, we gain a comprehensive picture of the order of importance, in point of time, of every detailed task. We find that some of the later operations should be started well in advance of many of the earlier operations. These schedules make it possible to plan the work effectively, to check the progress of this preparation as it is being done, and to make the most of all the available time.

Summary

It is plain that the detailed estimate is the major starting point of all the succeeding planning activities. With the estimate in hand and with a knowledge of the abilities and characteristics of the manufacturing processes and equipment, coupled with a full understanding of the requirements of the product itself, adequate operation lists and any necessary factory layouts can be made. From these operation lists, coupled with data in regard to the average amount of elapsed time needed to design and make the special equipment, definite time schedules can be set up for these tasks. With these schedules as a guide, the work of designing and making the special equipment may be spread over as large a force as may be available, while the actual progress of the work can be checked constantly, and steps can be taken when needed to avoid many possible delays.

CHAPTER IV

TOOL DESIGN

Tool design covers a wide field, and is divided and sub-divided into many specialties. This is one of the tasks of production engineering where "inspirational design" and "analytical design," adequately combined, have every opportunity of full play. Many texts are available which treat of the several specialized applications. Articles are constantly appearing in the technical press describing specific achievements, whereas others are devoted to pointing out the fundamental principles. Notable among these is the revised paper by Professor Roe entitled, "Principles of Jig and Fixture Practice," published in *Mechanical Engineering*, February, 1941, in which he lists several principles of design and definite characteristics of design which should be followed. In the following summary of tool design, the arrangement and discussion is largely an abstract, or "free translation" of Professor Roe's paper.

As noted before, the operation lists for the component parts give a catalogue of the tools needed to start the production of a new commodity. The time schedules for the tool design give the information which enables each task here to be started in proper sequence so as to meet a specified production schedule.

Considering the requirements of the special equipment, particularly the jigs and fixtures, there are several principles which should always be applied. Some of the more important ones are as follows.

Economic Principles

The answer to the question as to the amount of expense which is justified for making these tools involves many factors. One is the quantity of production. The larger the quantity, the greater may be the cost of this equipment without an increase in the unit cost of production. If by spending more on these tools we can reduce the time required for operation on the production floor, we can seek a balance between the greater cost of the equipment and the reduced cost of production. This may be relatively simple for new tools for a new product. Here we may be working on a definite budget. If the tool designer suggests a more expensive tool than the one originally selected, and its use for the production of a specified quantity will reduce the

cost of production as much as, or more than, the increased cost of the tool, then the budget for the tools should be increased and that for the actual production decreased accordingly. In this case, the tool designer is responsible for the accuracy of his estimate for the reduction in production time.

The problem of making new tools to replace old ones in use on current production, in order to reduce the cost of manufacture, introduces another factor. Here the residual value of the old tool must be added to the cost of the new one in order to obtain a true balance.

Again, certain refinements necessary to the functioning of the product may force the building of expensive tools regardless of the quantity of production. The cost of the tools must then be divided by the number of parts to be produced and the result must be added to the unit cost of production. Such a condition may exist when a definite order for a specific number of a special product is taken. Then additional orders for the same special product may be received, sometimes even before the first order is completed, and without any new quotation. With the tools already paid for, some adjustment in price should be made. When the total amount of production is unknown, the cost of the tools is high, and the work is for an outside customer, the quotation sometimes gives the cost of the tools separately. Then the cost of the product carries no tool charges other than the probable maintenance costs.

Tolerances on Component Parts

The extent of the tolerances on the component part, particularly if the amount is small, has a definite influence on the design and the required accuracy of the work-holding device. These tolerances are necessary evils and must allow for all variations on the component that may develop in manufacture. Only a small part of them can be consumed by inaccuracies in these jigs and fixtures. The smaller they are, the greater the accuracy needed in making the work-holding devices. Any unnecessary degree of accuracy specified for the component results in an unnecessary increase in the cost of the tools. In addition, to maintain a high degree of accuracy on the components requires rigid tools and machines, as well as extra care on the part of the machine operators. This often adds to both the expense for the tools and to the cost of production itself.

When the tolerances are extremely small, it may be essential to conduct the actual manufacturing in a department which has a controlled temperature. The expense of the air-conditioning apparatus is an additional charge against the cost of preparation.

Locating Points

The second rule of dimensioning with tolerances reads:

Dimensions should be given between those points or surfaces which it is essential to hold in a specific relationship to each other. This applies particularly to those surfaces in each plane which control the location of other component parts.

Many dimensions are relatively unimportant in this respect. It is good practice in such cases to establish a common location point or surface in each plane and give, as far as possible, all such dimensions from these common locating points.

In all cases, the locating points on the component drawings, the locating or registering points used for machining the surfaces, and the locating points used for gaging must be identical.

The tool designer should assume that the component drawings are correct, and use the locating points specified on them. If reasonable doubt should exist in regard to the location of any of these dimensions, he should call the matter to the attention of those responsible for the production design. Or if it is a dimension of secondary importance where a change in location would permit the design of a simpler and cheaper fixture, he should bring this up too. If the tool designer is working under the direction of a process engineer who is following up all the work of preparation on a given component, the process engineer should consult with the production design authority. But unless the component drawing is changed to suit the suggestions, the tool designer should locate the part as specified by the location of the dimensions.

Number of Operations at One Setting

The distinction between dimensions of size and of position has already been noted. Where dimensions of position are involved, the greatest accuracy is attained when as many of these dimensions as possible are machined at one setting of the component part, provided that they all have the same common locating point. Where dimensions of size are involved, the greatest accuracy coupled with the largest rate of production is generally attained on single purpose, single operation machines (where one surface only is machined at each setting).

Interchangeability of Fixtures

Fixtures should be interchangeable on the various machine tools on which they may be used. This, in turn, requires the standardization

of those elements of the machine tools that fit or match the clamping or locating elements of the fixtures. This is a subject which has received far too little attention. Manufacturers of similar machine tools have made no attempt to use standard sizes or common positions of T-slots on the machine tables or common spindle nose sizes or constructions, etc. In fact, some machine tool builders made no effort to keep these elements on new designs of machine tools the same as they were on their own earlier models. At the present time, under the procedure of the American Standards Association a definite effort is being made to standardize many of these machine tool elements which affect the interchangeability of tools and work-holding devices. The machine tool manufacturers are giving their full cooperation to this effort.

In the meantime, however, a complete record of the dimensions and positions of these elements on all the productive equipment in current use should be available for the information of the tool designer, and these factors should be considered when deciding which make of competitive machine to buy when new equipment is needed.

Marking of Special Equipment

All jigs, fixtures, and other special tools should be marked clearly. In some plants, the practice is to stamp the part and the operation numbers on the equipment. In other plants, a definite number or symbol, without any reference to the part or operation, is used. This identification mark is then recorded on the operation list for any component part which can use it. Sometimes much of this special equipment may be designed for use in the manufacture of several different component parts, and, to avoid the needless expense of duplicating equipment that is already available, a list of these semi-standard tools should be made. This is particularly applicable to special tools for such automatic machines as screw machines.

In one plant, the original practice was to make a complete set of tools for parts made on screw machines for each different component part, and, when they were not in use, to store the complete set of tools in special boxes, marked with the part number. After this practice was followed for many years, the space required to store these tools began to approach in area the space required for the screw machines themselves. Also, the amount of money tied up in these tools, many of them with duplicates, became excessive. This led to a certain degree of standardization of this equipment which eliminated most of the duplication, and reduced the amount of storage space required. It would have been better to start out in this way.

Standard Parts for Tools

Many elementary parts of jigs and fixtures can be standardized to advantage. Such parts include jig bushings, locking latches, handles, thumb screws, locating studs or seats, feet for jigs, and die sets and sub-press die frames. Many plants specializing in the making of tools have established such standards for their own use. Where a plant makes its own special production equipment, most of the standardization must be done there. Certain of these elements of jigs and fixtures are now being manufactured by companies which make such work their specialty. This holds true for jig bushings and for die sets and sub-press frames, for example. The American Standards Association has adopted standards for jig bushings, and for T-slots, their bolts, nuts, tongues, and cutters.

Work-Holders or Racks

Special tote boxes or special racks for holding the work between operations should be considered as an integral part of the tool design. Some of these tote boxes may be standardized, but others need to be designed for their specific purpose. The practice of dropping a nicely finished, delicate part into an open box does not improve the quality of the product. Such parts should be placed in suitable racks where they cannot touch each other. This will not only prevent marking or bruising of parts but it will also make possible a saving in time on the succeeding operation since, with all parts arranged in the same order, the operator saves the time required to handle the part and to turn it to the proper position for placing it in the work-holding device.

Requirements of Work-Holding Devices

A jig or fixture should:

(*a*) Locate the work quickly and positively.

(*b*) Preclude insertion of the work in any but the position correct for cutting.

(*c*) Provide rapid and positive clamping without undue effort.

(*d*) Allow no spring in work, fixture, or machine table from either clamping or the pressure of the cutting tools.

(*e*) Allow no slipping, vibration, or chatter during the cut.

(*f*) Have ample clearance for chips and be easily cleaned.

(*g*) Allow free access and egress for the cutting oil or compound.

(*h*) Be as light as is consistent with strength and rigidity, and easy to handle.

(*i*) Be safe for the operator. Production should be sacrificed, if necessary, rather than safety.

Requirements of Operation. The first three, (*a*), (*b*), and (*c*), of the foregoing requirements relate to the features of operation of the special equipment as it affects the time consumed by the operator. In the open or unlocked position of the fixture, the machined part should be easily removed. The locating surfaces should be visible to permit quick detection of any chips. It must be possible to insert and position the new part quickly. The clamping elements should force and lock the part against the locating surfaces.

It is desirable to design the fixture so that when a part is not positioned correctly, the work cannot be clamped, or so that it will not go into the fixture except when presented in its proper position. Sometimes this feature is carried to the point where if some previous operation has not been performed, or if too much material remains on the part, the work cannot be inserted. Here the fixture is in effect a part of the inspection equipment.

The prevention of improper positioning of the work is not always possible. For example, a punched blank of symmetrical form may have a bending operation, and the burr side should be up or down, as the case may be. Here no feature of design is possible which will prevent the blank from being inserted either way. We must therefore depend upon the attention and integrity of the operator to place it in its proper position.

Whenever possible, the jig or fixture should be clamped in a single, natural, continuous movement of one or both hands. To accomplish this involves the use of cam or wedge locks, equalizing bars, and many other ingenious contrivances which must often lock at different places in a predetermined order. Some use is made of pneumatic and hydraulic pressures and valves to attain this end. The use of several thumb screws or other screw locks should be avoided as much as possible. The employment of nuts or set screws which also require the use of wrenches is particularly to be avoided if rapid operation is desired.

Accuracy of Operation. The fourth and fifth, (*d*) and (*e*), of the foregoing requirements relate to the features of design which affect the accuracy of the machined product. It is evident that any spring in work or equipment from clamping or cutting destroys the potential accuracy of the cut. On milling cuts, for example, it is desirable to have substantially solid material between the bottom of the work and the machine table. If the conditions of location are such that the part must be registered against a surface on the same side as the milling

cut, a solid wedge should be used to force and hold the work in its cutting position.

In order to eliminate slipping during the cut, the part should be clamped against a solid portion of the fixture on the side or end that resists the thrust of the cutting tool. To prevent chatter, the machine table must be held so that the thrust of the cutting tool cannot change the position of the table. Hence for milling, the most common practice has been to have the direction of the feed against the direction of rotation of the cutting edges of the cutter. When the table is fed by a lead screw or cam, there is always some play or backlash in this feeding mechanism. By following this common practice, both the friction of the table and the thrust of the cutter act in the same direction to hold the driving surfaces of the feed mechanism in contact. The milling cutter itself is then working under the most unfavorable conditions. The chip from milling is of varying thickness, changing from virtually nothing at the start of the cutting to a maximum at the end. In action, the cutting edge of the milling cutter compresses the metal of the part until the force is enough to press the edge into the metal and start the cut. If the cutting is with the feed, and the force moving the table is a weight or spring, whereas the feed screw or cam acts only to control or hold back the movement of the table, then the thickest part of the chip is at the start of the cut and the heavy compressive pressure on the edges of the cutter at the thin end of the chip is eliminated. Under these conditions, the cut is smoother and the wear on the cutting edges of the milling cutter is less than when the conventional practice is followed. If a fairly deep cut is to be made with a thin slitting saw, this "climb milling" is often followed. To do otherwise would result in a buckled and broken cutter. This is possible here without taking up the backlash of the feed mechanism because the thrust of the thin cutter is not sufficient to move the machine table. Such a reversal of conventional practice has been followed for years in a few industries where the maximum of accuracy and smoothness of surface on milling cuts has been essential. It has been rediscovered recently, and is often used for the hobbing of gears.

Requirements for Chips and Coolant. The sixth and seventh, (*f*) and (*g*), of the foregoing requirements relate to the features which affect the disposal of chips and the effective use of the cutting compound. The locating surfaces of the fixture should be as small as the conditions permit and should stand above all surrounding material. All corners where chips may collect and interfere with the correct loca-

tion of the work should be eliminated. The construction should be as open as possible so that chips may be brushed away quickly.

The cutting compound serves a variety of purposes; among others, it serves as a coolant and lubricant for the cutting edges of the tools. With a copious flow, it also acts to wash the chips away from the surface that is being machined. It is obvious that in order to do this effectively, the fluid must be allowed to flow freely. The design of the fixture must permit the rapid draining of this coolant.

Human Factor of Operation. The eighth and ninth, (*h*) and (*i*), of the foregoing requirements relate to the human factors of operation such as minimum fatigue and maximum safety. When the jig must be handled manually, it should be as light as other conditions allow. If it must be heavy, then some construction or accessory device must be used to reduce the manual effort. Some jigs which must be turned over are mounted in trunnions; for some a rocker surface is provided to reduce the labor of turning them; some heavy jigs which must be moved to different positions are mounted on rollers; and for some an air hoist is provided to handle them.

Safety of operation should always be a matter of primary concern in the design of manufacturing equipment. All external corners of jigs and fixtures should be rounded to prevent injury to the hands of the operator. The loading position of the fixtures should be such that the operator's hands are never in danger from the cutting edges of the tool. Safety features such as removable guards over cutting tools, and two-hand starting levers, must, at times, be built into the machine tool equipment. These do not necessarily increase the production time. Frequently the extra time needed to operate the safety devices is more than made up by the increased speed of some other part of the manual operation, an increased speed that results directly from the feeling of greater safety on the part of the operator.

Maintenance Features

Jigs and fixtures should be designed so that all parts or surfaces subjected to wear can be replaced or repaired readily. The probable life of special cutting tools should be determined so that replacements are on hand when they are needed.

Gage Design

A gage should be provided whenever its use is more economical than the use of standard measuring instruments. For example, if the total production of a certain part amounts to about a dozen units, it would

be gross extravagance to provide any special gages. On the other hand, if this production amounts to several thousand units, a complete set of gages is both desirable and necessary. The extent to which gages are necessary, therefore, depends in great measure upon the amount of the total production. Furthermore, gages should be provided to check only those conditions which it is essential to maintain. The nature and extent of the gages required depend upon the manufacturing conditions. A check on one or two points is often sufficient to detect any unsatisfactory results. Under varying manufacturing conditions different faults must be guarded against. Gages are a preventive and not a cure. The point to be emphasized is that they should be provided whenever their addition will result in the production of more or better component parts with a total expenditure of the same or less effort.

There are two kinds of gages to consider, which for want of better terms will be called limit gages and functional gages. A limit gage is one that checks a specified dimension to specified tolerances. In other words, it is used to check dimensions of size. A functional gage is one that checks the relationship of several dimensions to insure the correct functioning of the assembled mechanism, and is one, therefore, which checks dimensions of position. As with other manufacturing equipment, the exact design of a gage is unimportant if it fulfils the purpose simply and efficiently.

The degree of accuracy required on the gage depends upon the extent of the tolerances on the product. In all cases, on limit gages, the variation should be inside the established limits of the component. The limiting dimensions given on component drawings are limit gage sizes. For example, the limits given for the diameter of a shaft should be interpreted to mean that this diameter must be made to satisfy ring or snap gages of the sizes specified.

Gages are an integral part of the manufacturing equipment and comprise that part the purpose of which is to measure the product, as distinguished from that part, the purpose of which is to change the form of the material or to hold the part during a manufacturing operation. Under this broad definition of a gage, it is apparent that some of the manufacturing equipment may be not only a holding device but also a gage. In fact, it is good practice to make jigs and fixtures so that an unserviceable part cannot be inserted. It often happens that when the normal manufacturing variations of certain machining processes are small and within known limits, a gage may be employed to test the size or form of the cutting tool, and not be applied directly

to the product. At other times, a gage in the form of a setting block for the position of the tool is made as an integral part of the fixture. Again, some types of grinding machines are fitted with sizing devices which stop the feed of the wheel when the work has reached a predetermined size, thus practically eliminating the need of continuous inspection. Therefore, to determine the character of the gages that are required for the production of any particular part, it is necessary to consider both the requirements of the parts in question, and the other manufacturing equipment that will be used for their production.

Limit Gages

Limit gages have two measuring elements: one to check the maximum metal size and the other to check the minimum metal size. These two measuring elements may be combined into one frame or they may consist of two separate gages.

Go Gages

The measuring element or gage that checks the maximum metal size is commonly called the "go" gage. This gage must go over, or enter into the part. These go gages control the interchangeability of the parts because they check the tightest condition of fit. As many elements as may be desired can be combined on a single go gage and effective inspection will be obtained. The go gages are always the most important of the limit gages. In some plants, successful manufacture of an interchangeable product has been maintained for years by the use of go gages.

The amount of wear on go gages is much greater than that on not-go gages since the go gages must assemble with every acceptable part, whereas the not-go gages must not assemble, and thus wear only from the contact they make with the rejected parts. The go gage is often made with a "wear allowance" which is added to the manufacturing tolerance required for making the gage. The direction of wear on these go gages is towards the outside, or away from the limits of the product. The extent of the wear allowance and gage tolerance depends upon the amount of the tolerance on the component and the expense of the gage. The wider the product tolerances, the greater the wear allowance may be, and hence the longer its life will be.

These gages may be of fixed size or adjustable, but some conditions of size or form do not permit these gages to be made adjustable. When gages are adjustable, no wear allowance is needed and these gages are readjusted to compensate for wear.

Not-Go Gages

The not-go gage checks the minimum metal size. These gages must not go over or enter into the part. They check the loosest fit conditions. On not-go gages, only one dimension or element can be checked at one time. If more than one element is represented on a not-go gage of fixed size, the gage will not go if any single element is within the product limits, although all the other elements may be well beyond the product limits. Therefore in order to have an effective inspection, every single dimension or element must have an individual not-go gage to test the minimum metal conditions. This often requires the provision of several not-go gages to complement a single go gage.

The direction of wear on not-go gages is into the component tolerance, hence no wear allowance is needed here. A rejection limit is often established for these gages so that the wear will not consume too much of the product tolerance. The manufacturing tolerance for the not-go gage is often much less than that for its companion go gage because its life is much longer, hence a greater first cost for it is justified.

Comparators

To reduce the time and expense of inspection, and to reduce the amount of product tolerance consumed by the gages, comparators of many types are used. These are adjusted to suitable size blocks or master gages. The size of the surface inspected is shown on a dial or other type of indicator, and the one inspection operation checks for both limits of size. As many elements as desirable may be checked at one setting of the part, different indicators showing the position or size of the different elements.

Where an extremely large rate of production is involved, special inspection and sorting machines are often built. The product will be fed into the machine and the parts will be sorted according to size by suitable indicating means and cooperating ejector mechanisms.

Where profiles and other composite surface sizes and positions are to be measured, optical comparators often prove to be most effective. Here an enlarged image of the form is thrown on a screen and compared with a suitable outline there. Where limits must be maintained, a double outline is drawn. The projected outline of the part must lie between these two outlines which represent the limiting conditions.

Functional Gages

There are many conditions of relative positions, such as straightness and alignment, which it is impossible to define precisely by means of

dimensions and notes alone. All such requirements are best defined in terms of a functional gage which represents the conditions of operation or assembly. These functional gages may represent some small part of the mechanism or they may represent a complete operating unit. For example, in the manufacture of large guns, one of the most important parts of the gaging equipment is a functional gage which is called the dummy breech mechanism. This is a complete and operating model of the actual breech mechanism. Parts from current production are substituted for the corresponding model part, and the mechanism is operated to check the performance of the manufactured part in combination with the other parts of the dummy mechanism. This represents the most elaborate type of functional gage.

At the other extreme, a part having two or more shoulders of different diameters may be required to enter freely a gage consisting of two concentric holes. The diameters of these holes in the functional gage should be larger than the maximum metal sizes of the part by at least one-half the amount of the allowance. This would insure that the conditions of concentricity and alignment were within sufficiently close limits to permit the part to assemble readily.

As another example, the relative positions of a group of holes could be checked by a functional gage consisting of a plate with projecting studs accurately located. The diameters of these studs should be smaller than the minimum limits of the holes by amounts not less than one-half of the minimum clearances or allowances.

In principle, the functional gage is designed to approximate, as closely as possible, the assembled or operating conditions of the product. Such representations are simplified as much as possible. Inasmuch as these functional gages specify the conditions which must be met much more definitely than any notation on the component drawing can possibly do, they become, both in theory and in practice, an essential part of the component specifications. When written specifications for each component part are not made to supplement the information given on the drawings, some reference should be given on the component drawing to call attention to these functional gages. For example, a note, with suitable arrows indicating the surfaces in question, might read: "Concentricity and alignment must meet requirements of functional gage No. GF-6295." Where written specifications supplementing the component drawings are prepared, a list of all the gages, including the functional gages, should be included.

Cutting Tools

Most cutting tools, both standard and special, are purchased from companies making a specialty of their manufacture. Usually, only the

form and size of the special cutting tools are sent to them. All other details of design are left to the discretion of the cutter manufacturer. When a selection from several different types must be made, the cutter maker may refer the matter back to the customer. At other times, the cutter manufacturer will generally choose the type which it is easiest and simplest for him to make. Take the problem of special-formed milling cutters, for example. The gashes or cutting flutes in these cutters may be straight or helical. Again, the shape of the cutting side of the gash may be radial or undercut. These undercut flutes are sometimes called hook flutes. The simplest cutter to make is one with straight radial gashes, but this one may not be the most effective for the particular service. Three other combinations are possible, and at times it is necessary to specify the particular combination required.

For a flat surface or shallow profile, where the most essential cutting edges are substantially on the outside circumference of the cutter, the helical flutes will give a smoother cut. Here a radial form of gash is generally adequate unless the material is one such as aluminum which needs a keener cutting edge than some other metals, when an undercut flute will give this keener cutting edge.

For milling a slot or a profile where the most essential cutting edges are on the sides of the cutter, an undercut gash will give the smoother cut. Where the width of form is slight, or where most of the cutting is done by the sides of the cutter, a straight gash will be adequate. This will also be the easier form to make and to resharpen.

For milling forms where the essential cutting edges are on both the outside and sides of the cutter, helical flutes with undercut gashes will give the smoother cut.

The milling cutter with straight flutes and radial gashes is the simplest to make and easiest to resharpen. In most cases, it also has the most substantial cutting edges. This is the most common form of milling cutter and it proves satisfactory for the great majority of milling operations.

The Tool Designer

In the early days of interchangeable manufacture, which was the beginning of our present mass-production methods, the factories were generally organized, in effect, as a combination of many small shops. Each small shop or department was operated by a contractor, and produced some element or unit of the product. The company furnished the buildings and power and standard equipment, and generally the raw materials for the product. The contractor, working under a definite contract to produce the unit at a definite price, furnished the special equipment, hired the labor, and operated his department. The company

advanced the money required to meet the contractor's payroll, etc., and credited him with the contract value of the parts he produced. An accounting was made periodically. If the contractor was still in debt to the company, he received nothing. If the balance was in his favor, he received this balance. This was known as the "contract system."

Under the contract system, the contractor, with a few mechanics to assist him, made all plans for the production of his unit, designed and built the special tools and much of the special machinery required, operated his department, and experimented and searched constantly for ways and means to reduce his cost of production. Any reduction of these costs added directly to the income of the contractor. Each contractor had a group of machines, a small tool room in effect, for making and maintaining his productive equipment.

During the period between 1890 to 1900, or thereabouts, these contract systems were abandoned. The departments were left substantially as before but were operated by foremen or superintendents on fixed salaries. The special tool-making equipment began to be collected in a central tool room where tools for all departments were made. The tool maker both designed and made the tools. A part would be given to him with orders to make all the tools necessary to produce it. He himself would plan the series of manufacturing operations, and then make the tools. Drawings were the exception and not the rule. The tool maker might make some sketches, but he generally worked out the details as he went along. Discarded and obsolete work-holding devices were often altered and worked over into new tools.

Some of these tool makers were more ingenious in the design of tools than others, so that about 1900 many of them were persuaded to study mechanical drawing. This enabled them to devote all their time to the design of new tools which the other tool makers could build. The earlier drawings were made on paper and then varnished or shellacked to protect them from oil and dirt while they were used in the shop. Although blueprint paper was first invented in 1840, a cheap process of making it was not developed until about the end of the century. With a cheap method of reproduction, tracings and blueprints soon came into wide use. Possibly this too had an influence on the separation of the tool design from the tool making.

Today, our tool designers come from many sources. Some start in trade schools or as apprentices, become mechanics and tool makers, and are transferred to tool design. In this they follow much the same course of training as did the original tool designers. Others may start as tracers and detailers in the drafting room, then design simple tools

under the supervision of more experienced men, and eventually become tool designers. Many of the men who start in this way are graduates of engineering schools, starting their practical experience in the drafting room.

For those whose shop experience is limited, any plan which helps them to enlarge their acquaintance with the shop and its problems will act to make them more effective in their work. Definite opportunities should be given to these men to follow up the actual making of the tools they design, and they should have opportunities to observe the actual performance of this special equipment.

Requisitions and Schedules for the Tool Room

The number of tools required to meet a definite production schedule and the latest dates when they should be started and finished should be determined before the tools are designed. After the tool design is completed, however, the process engineer in charge of the preparation work on a given component part should himself make sure that the actual requisitions are made out and that these with the tool drawings are sent to the order department or purchasing agent. Furthermore, he should check to be sure that the orders are actually issued and sent to the tool-making establishment.

Whether this special equipment is made in the tool room in the plant or in the plant of an outside contractor, the process engineer should know the order number and the place where the work is to be done. He should also visit, either in person or by proxy, the shop where the work is placed, and should keep himself informed of the progress of the work. He should, in every way possible, promote the completion of the job.

If other conditions permit, some of this detail of follow-up could well be delegated to the tool designer who designed the tools. Whatever the routine followed, the process engineer in charge of a given part of this work of preparation must be able at any time to give a complete and accurate report of the existing progress of the work. If this progress is falling behind the schedule, and his own powers are not sufficient to correct the situation, he must report to his immediate superior as soon as any lag is apparent or probable. This will give an opportunity for the needed pressure to be exerted at a time when there will be some chance to catch up. Here again, notice and explanations before a probable delay or departure from schedule are far more valuable than excuses afterwards.

CHAPTER V

PROVING THE PRODUCTION DESIGN AND EQUIPMENT

During the planning stage of the production of a new commodity, this product generally exists only in the form of drawings. An experimental model may be in existence, but many changes have been made during the development of the production design. Drawings are made of each component part and these details have been derived from the assembly drawing. Hence in the planning, we start from the assembled product and break it down into its component parts.

Again, for each detail, we start from the completed component part and plan each operation necessary to produce it. The jigs, fixtures, cutting tools, and gages are designed to carry through these plans.

When we start the actual production in metal or other material, on the other hand, we begin with the material in the form of castings, forgings, bar and sheet stock, etc. Then we have a large collection of special work-holding devices, cutting tools, gages, and the machine equipment of the plant. These tools are mounted on the machines and adjusted, then the raw material for a given part is clamped in the work-holding device for its first operation, and the first cut is taken. Then it is passed successively through all the succeeding operations and finally emerges as a finished component. In other words, on the production floor the sequence is the exact reverse of that of the planning.

A similar difference exists in the mental attitude of the planning group and that of the production group during the initial production. In planning, the functional operation of the product is the primary concern. Efforts are made to modify the design to facilitate its manufacture as much as possible without detriment to its functioning. On the production floor, the primary thought is to facilitate production alone. The functional requirements of a new product are almost unknown quantities in the early stages of the work. It is only when some samples of every component part have been finished and actually assembled that the production group begins to appreciate and to understand the functional significance of the details. As Mr. Pedersen states: "In the assembling department, however, the sins of faulty production design now overtake us."

Manufacturing Model

One effective way to prove the production design and to minimize the delays caused by corrections after the first machine-made parts have been completed and assembled is to make one or more manufacturing models in the machine shop or model room to the specifications of the production design. This practice is followed in a few plants, although it proves to be a very effective one.

In the majority of plants, however, such a practice is rejected on the ground that it adds unnecessary expense and that it involves unnecessary delays. This has not been true in the few plants where this practice is followed.

It is a curious fact that plants which make machines in small lots find it profitable to push the manufacture of a single pilot machine of a new design ahead of the rest of the first lot, to catch possible shortcomings in the design; but plants about to produce a new model in large lots or on a continuous production schedule consider that it takes too much time or costs too much to make these manufacturing models which will catch the majority of the mistakes before they happen.

Such manufacturing models serve a further purpose after they have proved the production design. They constitute in themselves effective functional gages for every component part. If any question arises about a machine-made component, this part may be assembled into one of the manufacturing models and tried out there.

Procurement of Tools

When a definite production schedule must be met, it is most essential to have a complete and continuous check on the progress of the making of the jigs, fixtures, gages, and other special tools. Unforeseen delays are always probable. The tools for operations 6 and 7, for example, cannot be tried out until all the tools for the preceding operations are received and set up. When there are both regular and emergency tool rooms, delays can be minimized or avoided by taking from the regular tool room partially finished tools whose production has been delayed by any cause, and completing them in the emergency tool room.

When tools are made by some outside tool plant, and reasonable notice is received of a probable delay in the completion of any of them, it is often possible to plan for and to make some temporary tools to carry the work along until the regular tools are received, particularly if they are tools needed for some of the earlier operations.

Delivery schedules on special construction are always difficult to maintain. This is particularly true when the tool manufacturers, in

common with most other manufacturers, tend to promise what they think the customer wants to hear rather than what they are sure they can perform.

Checking of Tools

All new tools should be checked upon their completion, or when they are received from an outside source. Many can be checked by direct measurement. Others may best be checked by the measurement of the product they produce. Some cutting tools need to be checked not only when they are new but also after each resharpening.

Not many years ago, an automobile manufacturer brought out a new model. Among the changes was a new spiral bevel gear drive in the rear axle. In this design, the bevel pinion was so small that the clearance at the roots of the teeth had been reduced to leave a little more metal here. A few months after the new model was on the market, over a thousand of these rear axle gears had been returned from service stations because they were too noisy. At the same time, the assembling department was finding it extremely difficult to adjust these gears so that they would run quietly. An investigation revealed the following. When the gears were cut, the entering corner of the cutter did the most work and wore the most. When the tools were resharpened, all the worn corners were not removed. As a consequence, the fillet at the bottom of the tooth form was carried farther up the tooth profile than the normal distance. When assembled with the mating gear, the entering corner of the gear tooth made premature contact with this fillet, and the interference caused excessive noise. An immediate but temporary correction of the condition was made by resharpening the cutters until all of the worn corners of the cutting tools were removed. The permanent correction was made by a redesign of these gears which permitted the use of the full amount of the normal clearance.

Set-up of Operations

The setting up of the equipment for each operation includes the attachment of the work-holding device to the work table of the machine, the mounting of the cutting tools into the spindle of the machine, the adjustment of the machine so that the finished sizes are correct, and the actual operation of the set-up to check the estimated rate of production. With automatic machines, stops must be adjusted, cams mounted and positioned, multiple tools adjusted in relation to each other, etc.

When the set-up is completed, it is sometimes apparent that the equipment is inadequate. The required degree of accuracy cannot

always be maintained for all surfaces machined during this operation. In such cases, some temporary supplementary operation may be introduced, for which the necessary special equipment is improvised. At other times it is clear that sufficient chip clearance is not present, or that it is difficult and slow to insert and remove the work, or that the clamping device is too slow in operation, or that the work is not adequately supported or clamped. We can sometimes proceed at a greatly reduced pace until the tools are corrected or new ones are made or the operation will be at a standstill until new and adequate tools are ready. For this last condition, the existence of an emergency tool room is a life-saver.

As one example: A counterboring jig, on completion, gave a production of less than one-half of the estimated amount. It took too much time to load and unload and to clean out the chips. This jig was used, however, for a couple of weeks until a new jig could be designed and built. The new jig was designed with ample chip clearance, and the work could be rapidly inserted and removed. As a matter of fact, the extremely poor showing of the first design was a spur to design the most effective tool possible for the job. When the new jig was put into operation, the rate of production was nearly double the amount first estimated, and the reduction in the cost of the operation more than paid for the original mistake.

As a second example: On a visit to an automobile plant a few months after production on a new model had started, a group of machines with make-shift equipment was noticed in a corner near a stairway. Some of the machines and most of the equipment looked as though they had been salvaged from a scrap pile. The plant was arranged for line production. The flow of several parts was interrupted at some point in their line, and the parts were carried to this make-shift equipment, and then returned to the regular line. My guide, the shop superintendent, when asked about this equipment, started to tell me what operations were performed there, and then stopped. He took out his notebook and made an entry. He then confessed that some of the equipment for some operations did not prove adequate, and that some burring and other minor operations had been forgotten in making the original operation list. The production group had intended to correct these conditions as soon as the stress of starting was over, but after living with them for several months, the conditions had come to seem normal, and the correction had been forgotten. He promised me that if I returned in a few weeks, I would no longer find this make-shift equipment in evidence.

Checking Tool-Made Parts

When adequate functional gages are provided, the first parts produced from the tools can be checked definitely for interchangeability and often partially for their functioning. Some conditions of operation, however, can only be definitely proved by actual service tests of the assembled product. Nevertheless the sooner any possible fault can be detected, the sooner it can be corrected. If all faults are undetected until after the final assembly and service testing, the delay in the start of production will be greater than when they are discovered earlier. The most effective type of functional gage for this purpose is a manufacturing model.

For example, a part was made of sheet steel which had a bent and formed end which acted as a cam for a mating part. When some of these parts were assembled into the manufacturing model, some of them operated smoothly while others did not. An examination showed that when the burr side of the blank was on the outside of the bend, and not on the cam surface, the parts operated smoothly. The blank was symmetrical in form. No information was given on the component drawing about the correct position of the burr side, and so parts were bent either way. This omission was corrected on the component drawing, the operator on the forming operation was instructed to keep the burr side of the blank up when it was placed in position for bending and forming, so this fault was corrected before many parts had been made.

Initial Assembly of First Tool-Made Parts

When manufacturing models are not available, we must wait until some of all the component parts have been produced before we can detect many conditions that interfere with interchangeability and operation. Conditions at assembly show definitely whether or not the maximum metal sizes have been properly established and maintained. In fact, for both new and old products, a survey of the assembling will soon show how effective the shop inspection has been.

All minor details which have been overlooked in the earlier stages of the work will rise up to trouble us here. Forgotten corners and sharp edges which should have been rounded or burred to facilitate assembly will soon make their presence known. Some of them may involve extensive changes before they are corrected. Unless careful attention is given to every detail, both major and minor, in the preliminary work of preparation, almost everything that can happen will happen here.

As an example, a hand hole was needed in the base of a machine

for a certain adjustment. After the machine was assembled, room for only one hand would be sufficient. The base was designed accordingly. At assembly, however, two hands were needed to put some of the parts together. This hand hole had to be cut larger on all the finished bases in order to salvage them. The drawings and patterns were changed to provide the greater amount of space needed on the succeeding product. The covers for these hand holes were scrapped, and new and larger ones were made.

Testing New Product

The final proof of the adequacy of the work of preparation is not established until after the assembled product has been actually tried out in service. Such tests should include not only the performance of the product when new but also its behavior after continued service. Durability is one of the important elements of quality. Resistance to wear, corrosion, and fatigue are often major factors of durability. Exclusion of dust and dirt, as well as permanent sealing against the leakage of oil may also be essential elements to the satisfactory performance of the product. Overload tests, accelerated wear tests, and operation under extreme conditions of heat, cold, humidity, or dust may sometimes prove themselves adequate to obtain a good measure of durability, but a long-time continuous service test may be needed to prove these characteristics. Where several manufacturing models have been made one or more of them may be subjected to such service tests which will be progressing during the time that plans for manufacturing are being made and carried out. Here is another place where the construction of models will give us essential information sooner than it can be obtained in any other way.

As an example: A manufacturing model of a new power-driven household appliance was undergoing a continuous run test to prove its durability while the preparation for production was in progress. One vertical shaft mounted in the die-cast gear box ran in an oil-less bearing. The end of this shaft and bearing was exposed at the top of the gear box. Preliminary tests indicated that no oil would leak out of the gear box even when the unit was inverted for a long time. Under continuous operation, however, oil began to leak through the bearing. With continuous running, the oil became warmer, its viscosity decreased, and capillary attraction carried it up between the shaft and the bearing. An investigation showed that there was very little clearance between the hub of one unit on this shaft and the bottom of the bearing. The splashing oil collected here and its meniscus sealed the bottom end of the bearing. This condition was corrected by in-

creasing the clearance between the hub and the bottom of the bearing by shortening the bushing. In addition, a wide slot was made through the boss of the die-casting which provided an open channel for draining off the excess oil. The core for the die-casting die was corrected accordingly before any great number of castings had been made.

This same appliance had a central vertical tube through which two shafts operated. One was hollow and oscillated. The solid central shaft revolved at a constant speed. Shortly after the leakage of oil from the gear box was corrected, oil was discovered at the top of this central tube, some fourteen inches or so above the gear box. An investigation disclosed the following information. The operation of the gear box created heat which built up a pressure in the gear box equal to about one-quarter of an inch of water. The only place for this pressure to escape was through the central tube. From time to time, the splashing oil would make a temporary seal at the bottom of the tube. The pressure would cause a bubble of oil to form which would travel up the tube a short distance before it broke. As this oil drained down, it would form another seal a little farther up. Another bubble would be formed, and the same process would be repeated. Eventually the bubble would reach the top of the tube and discharge the oil there. An examination of several units which had been operated for different lengths of time showed a mottled appearance, caused by the collected oil, at different heights. The particular height was in substantial agreement with the length of time during which the unit had been operating. This condition was corrected by mounting a disk or washer on the revolving shaft to act as an oil slinger. The centrifugal force acting on the oil at the rim of the oil slinger was greater than the pressure in the gear box. An examination of units so equipped and operated continuously for some time showed that no oil whatever entered the central tube. Conditions such as these can seldom be foreseen. Actual running is our only source of information.

Perhaps most unsatisfactory conditions which are revealed by actual service tests should be foreseen, yet many of them will escape our attention. An example of this is the following: The specifications for the breech block and breech recess for a large field gun called for a buttress thread form to lock the breech block. The original specifications gave no clearance on the non-operating surfaces of the thread. After the proof firing, the breech block was locked so tightly in the breech that it had to be unlocked with a sledge hammer. No machined surface is ever absolutely smooth and perfect in size and form. The "set-back" of the firing resulted in plastic flow of the materials. This made the mating locating surfaces to conform to each other. Some of

the displaced material, however, jammed against some of the non-operating surfaces because there was no other place for it to go. After the component drawings and gages were changed to give liberal clearances on all non-locating surfaces of this thread form, and all finished parts were altered accordingly, this fault was corrected.

The tendency in dimensioning component drawings is to give some surface easily measured with a close or small tolerance, in the hope that this will insure accurate production of the entire surface of which the specified dimension is but one element out of several. This was done for the cam form on a cam shaft of a new automobile engine. The largest and smallest dimensions over the cam, which could be easily checked by snap gages, were given with tolerances of about one thousandth of an inch. When the first new engines were assembled and put on test, the timing of the valves was erratic and incorrect. The master cams in the cam-grinding machines were rechecked and found to be correct. Yet the finished cam shafts continued to show errors in timing. The grinding operation was on piecework. After considerable searching, it was discovered that the grinding operators would shift the set-up when any cam lobe had more metal on one side than on the other side which had to be ground off. With the close tolerances on the over-all dimensions, if the amount of material to be removed was not symmetrical on the entire surface of the cam lobe, it would take more time to bring them to size. But shifting the work to correct this condition for some of the lobes on the cam shaft spoiled the timing. The close tolerance specified was not necessary to the functioning of the engine because there was an adjustment for the position or amount of opening of the valves. The relation of the angular positions of the cam lobes was the most essential functional condition. This fault was corrected by giving a liberal tolerance to the over-all sizes of the cam lobes, and by providing a revolving functional gage which checked the angular position of each lobe by comparison with a master cam. Under these conditions, the operator finished each cam shaft at a single setting, and stopped grinding on each cam lobe when the cam surface was completely finished. This took no more time than before.

There will occasionally be a surface which needs exceptional care in its production, either for size or smoothness. The most essential move in obtaining such conditions in production is to convince thoroughly the foreman and workmen who must produce it that these conditions are actually needed. Without such a firm conviction, the production force will always question the need of extreme refinements, and will make only half-hearted attempts to achieve them. This is only natural because extreme refinements are called for more often

than they are actually needed. Once the workmen are convinced of their necessity, however, it is a continual source of amazement to me to see the nicety and consistency of craftsmanship which a shop will produce.

Problems of Preparation

The major factor of preparation is detail, endless detail. The more extensive the project, the greater the amount of detail. Thus the problem of changing over an entire plant to make an entirely new product will be far more complicated than that of introducing one new product which involves only a small part of the total productive facilities of the plant. An organization which can handle a small amount of new work may prove entirely inadequate to the task of changing the production of the entire plant. On the other hand, if this group is well organized and led, and works consistently along definite lines, the size of the task will make little difference except for the amount of time required to do the work.

The most difficult task of preparation is met when the production of an entire plant must be shifted to a new product. Such situations are relatively rare. They exist most generally in times of national emergency when, for example, an automobile plant may be called upon to produce airplanes or machine guns. The design authority and the final inspection authority are then entirely independent of and distinct from the preparation and production authority. A production design may or may not be available. If not, it must be developed as the operation lists are made and the tools are designed. Even so it will be hardly more than half done. To make the job harder, all suggested changes must be approved by the design authority. Too frequently, this approval is hard to get because the design authority is likely to assume that these requests are made with ulterior motives. Even when a production design is available, it is not necessarily adequate or complete. The only conclusive test of a production design is its actual production under mass-production conditions. Most of these new products will never have been actually produced in large quantities. Some may have been produced in small lots, but a design which is adequate for such conditions of production is seldom the best answer for the conditions of mass production. This condition should be recognized in the contract, and a definite procedure set up to handle it, but all suggestions along such lines have been indignantly rejected. The contract assumes that all specifications are complete and perfect. This situation is responsible for many delays in the start of production.

Again, for many of these new products, only experimental models

have been made and tried out. Thus for all such projects we start under a heavier handicap than we do when we are preparing to manufacture a product of our own design.

In addition, if we do not have an organization which is already trained in the minutiae of preparation, we must organize one for the purpose. The members of this group may be drawn from the engineering force in the shop. There is, however, considerable difference between the technique of preparation and that of control. Some persons may be effective on one type of work and ineffective on the other type. In some respects, the preparation or starting of a new product needs radicals whereas the orderly and continued production of an existing product needs conservatives.

A task of similar difficulty exists when it is necessary to prepare for the production of a major change in the design of an existing product when it is a change that affects the whole plant. Here however, the design authority is an integral part of the organization. This makes for more rapid decisions, less delay, and generally for more effective cooperation. In both changes, however, the size of the plant affected is an important factor. The larger the project and the larger the plant, the greater the amount of detail which is involved, and the greater the length of time before production is started. Given an adequate production design, a large project distributed among a number of smaller plants will make a much faster start than the same project concentrated in a single large plant. On the other hand, if the production design is not adequate, the distribution of the task among several plants will make a bad matter worse.

When a plant, large or small, produces a wide variety of products, with the frequent introduction of a new product which affects only a small proportion of the total production, a permanent preparation group is generally organized. Here the preparation is handled as a matter of routine, and is carried through effectively. In other words, practice makes perfect.

The majority of large production plants manufacture specialties of reasonably stabilized design, and only minor changes in a small part of the product are ordinarily made at any one time. This task of preparation is simple, and is often handled without any special organization. One or more persons may be temporarily transferred from their regular duties to follow the changes through, or the work may be handled by the regular staff in addition to their routine tasks. Although time is important, it is not essential. The production of the existing product can be continued until the changes are completed.

Organization for Preparation

As would be expected, the extent of the organization for preparation in any plant depends upon the amount or the frequency of changes in production. It may be of interest to consider briefly the organization of a few plants as it relates to the stability of the design of their product and their organization for preparation.

As the first example, we will consider a large producer of electrical equipment. This organization manufactures a wide variety of standard electrical equipment and many other items which have been developed as a by-product of extensive research in its special field. The inventive or functional design comes from the research laboratory. The manufacturing activities are divided into two departments, the manufacturing engineering department and the operating department. Several plants are operated, some of them manufacturing duplicate parts. The product is subjected to frequent changes, some consisting of major changes in design incorporating improvements and refinements in functioning, and others resulting from the development of improved production processes and the substitution of more economical manufacturing methods. An increase in the amount of production of some items will raise the question of whether to increase the amount of the existing type of equipment to handle this increase or to develop a more effective process to do it all. Change is the rule here and not the exception.

The manufacturing engineering department starts with the functional design and carries the work through until actual production is under way. This department is subdivided into several sections, each of which deals with a specialized part of the task, and it also has sections which specialize in many of the supporting activities of both preparation and production. The general set-up of this work is a well-balanced system of centralized control of policy and general methods, with decentralized attention to supporting details.

The operating department concentrates on production. This department takes over its task only after the manufacturing department has demonstrated that the preparation is complete and adequate. If trouble develops with the continued operation of any part of the work, the operating department will turn it back to the manufacturing engineering department to operate until the trouble has been corrected. This company probably handles more individual items of changes and preparation than any other one in the country, and handles them extremely well.

At another plant, the equipment engineer's office starts and follows

up all preparation activities. New products and major changes are relatively rare. This group is therefore increased and decreased in size in relation to the amount of work in hand. When a large task is to be done, men may be borrowed temporarily from other departments until the work is done. The estimates and the operation lists are made in this office. The tool design is done in the main drafting room under the supervision of the member of the equipment engineer's office who is charged with following through the preparation for the particular component part. Requisitions for the orders for tool design and for the making of the tools are made out by this same person. New tools are made in the tool shops, and their progress is followed closely by the engineer in charge of the part. There is an emergency tool room here, mostly engaged in emergency repairs to existing equipment, but if the completion of any tool in the regular tool shop is delayed for any reason, that tool will be transferred in its existing state to the emergency tool room for completion. When the tools are completed, they are delivered to the shop and set up by the regular machine adjusters there under the supervision of the man who followed them through. This engineer keeps in touch with the production until the foreman on the job is satisfied with the performance of the equipment.

The organization in one typewriter plant is as follows. The functional design is made by an experimental department which is independent of the manufacturing plant. Minor changes are made frequently. A production design is made from the experimental one. Then several sets of parts are made in the model room. These parts are assembled and tried out in the assembling department. When they are proved to be correct, operation lists are made and the new tools are designed in the drafting room. The tools are made in the tool room and delivered to the shop where they are set up and put into service. The schedule for the time when they will be put into operation is made in the office of the shop superintendent. There is no direct follow-up of the preparation by a single person but, cooperation between the drafting room, tool room, and shop is very close, and any foreman or workman who has any question will go directly to the person responsible for information.

Every manufacturing difficulty in the shop is investigated by the draftsman who is responsible for the component drawing. If any part of the trouble can be laid to the incompleteness or indefiniteness of the component drawing, a revision is immediately made to overcome the fault. Every effort is made to have the information on the drawings so definite and complete that if the present working force were lost or

dispersed, others could come in and pick up and continue the work with a minimum of difficulty.

Entirely new models which affect the equipment of the whole plant at the same time are rare. Some years ago, however, an entirely new model was brought out which required an almost complete change-over of the equipment. The general plans and schedules were made by the shop superintendent, chief draftsman, and the foreman of the tool room. The complete functional design was furnished by the experimental department in the form of one complete model and an incomplete set of drawings. One draftsman started to make the production design under the supervision of the shop superintendent and chief draftsman. The unusual completeness of the old component drawings was an invaluable guide in every respect. In about two weeks, this work had progressed to the point where the model room could start to make a dozen sets of parts. The design could be broken down into sub-assemblies which could be assembled and tested individually. The parts for each sub-assembly were sent to the assembling department for assembly and test as soon as they were finished. As soon as the production design for any sub-assembly was proved, other draftsmen started to design the tools. When these designs were completed, the tool room started to make the tools. With the exception of the size of the task, this job was carried through in the same manner as other routine changes.

The progress of the work was checked constantly against the schedule which had been prepared for it. The original schedule set a time of nine months for the completion of the work. When any part of the work fell behind the schedule, the group involved worked overtime for two or three nights a week until the lost time was made up. At the end, the time ran over the scheduled date for completion by two or three weeks. This schedule, incidentally, gave about one-half the elapsed time ordinarily spent on such a task. In addition, after the production of the new model had been under way for two or three months, it was running as smoothly, or even more smoothly, than the production of the old model had ever run.

The tendency in some automobile plants is to keep the engineering department busy with many tasks related to product development, thus keeping them in the field of functional design, and to give to the manufacturing departments the double task of preparation and routine production. Here the manufacturing department will have a tool design group where the operation lists and tool designs are made. Most of these plants have reduced their tool room capacity to that required for the maintenance of tools in service. When a new model is made,

most of the new tools are farmed out to outside tool-making shops. When an unusually extensive change is made, the tool design for some of the parts will also be done by outside companies. When new machine tools are needed, the manufacture of these machines is often required to furnish the equipment completely tooled to produce a given component part. Little definite effort is made to make a production design before the tool design is started. The component drawings used in the shop are generally made by the engineering department. Even when the manufacturing department makes the component drawings, they must be approved by the engineering department before they are issued for use. Minor changes are continually made, but major changes are combined into a yearly "new model."

In many of these plants a considerable chasm exists between the engineering and manufacturing divisions. Changes to facilitate manufacture are often rejected until it has been proved to be almost impossible to proceed without them. Although this industry has developed mass-production methods for medium and large parts to a remarkable degree, very few, if any, of these manufacturing plants have organized their preparation for manufacture as completely and effectively as has been done by the large producer of electrical equipment mentioned first.

In the metal working industry, in general, the most attention has been given to product development, process development, and routine production. Preparation for manufacture, as a definite specialty, has been almost ignored. It is only when new products and other major changes have been forced upon them, together with a limited time in which to prepare, that they become conscious of this weakness in their organization.

SECTION 2. PRODUCTION OPERATION AND CONTROL

CHAPTER VI

PRODUCTION

Effective production needs the coordination and orderly direction of all phases of four principal factors: personnel, product, processes and plant.

There are several types of production, each of which makes different demands upon the handling of the different factors. For one we have the continuous production of a single specialty where practically all the productive equipment is balanced for a definite rate of production and is set up permanently. Minor changes may be made from time to time, but the design is substantially stabilized and radical changes are the exception. The production of most office and household mechanical equipment such as clocks, watches, sewing machines, vacuum cleaners, mechanical refrigerators, washing machines, guns, bicycles, typewriters, adding machines, and metal files, belongs in this class.

Another type, similar in many ways to the first, but one whose design has not yet been as nearly stabilized, is represented by the production of automobiles, many kinds of agricultural implements, airplanes, and airplane engines. In this group, frequent or periodical changes in the equipment are made to take care of partial or complete changes in the design of the product.

A third type of production involves the making of a wide variety of sizes of the same type of product, or the production of a wide variety of products, generally of somewhat similar characteristics. Here the equipment is set up for the production of a specific quantity, or lot, and is then torn down and set up again for the making of something else. The production of electric motors of various sizes, electrical switches, fixtures, and other electrical equipment, valves, fittings, steam gages, telephone equipment, and most of the standard machinery belongs with this type.

A fourth type of production exists for the making of many kinds of specialties for a changing market; changes required to meet new styles, fads, or a change in general interest. Closely allied with these are

products which are made to fill a seasonal market. The making of toys, wearing apparel, and many novelties belongs in this group. Here we have frequent changes with few returns to a former set-up.

Personnel

Regardless of organization charts, contracts, agreements, or other formal written statements of relationships, obligations, and responsibilities, any organization is nothing more or less than a group of individual persons who spend a large part of their waking hours working in the same place in the attempt to accomplish some common task. Personal feelings often affect their actions more than reason or logic. This holds true for all, from the top to the bottom. Common sense is the rarest sense that is used. "Common sense is the gift of the gods to the chosen few—I have only a technical education!"

Here we have a cross section of our social and political society. Every virtue and vice of society in general has its counterpart here. Greed and altruism, politics and graft, cooperation and self-seeking, fraternity and snobbery, knowledge and bluffing, honesty and dishonesty—all make part of the problem. Many problems which appear on the surface to be technical in character turn out to be problems in human relationships.

The most pernicious condition that can exist in any organization is the presence of active cliques or rampant shop politics. Effective cooperation is practically impossible under such circumstances. These conditions exist, unfortunately, in too many organizations, both large and small. In general, however, active shop political parties develop to a greater extent in large organizations than in the smaller ones.

As a definite example: one plant of a large organization made a product for which a second plant of the same organization made one of the units. The product was not entirely satisfactory, partly because of the performance of the independent unit and partly because of the method of its attachment to the product. Orders were issued for the necessary experimental work to discover an adequate correction. Several months elapsed, and the situation appeared to be unchanged. Then an outside consultant was called in to study the problem. Every suggestion which the consultant had made had already been tried out. After about a week, it was evident to him that the general character of the correct solution was known, but that nothing was being done about it.

Other information also came to his attention. Some years before, the chief engineers of the two plants had both worked together in the same plant but had belonged to opposing groups or different political parties.

The chief engineer had made suggestions for the correction of the unit, while the chief engineer of the second plant had made suggestions for the correction of the method of attachment. These suggestions were the ones that should be followed, but neither engineer would admit the value of the other's suggestion or adopt it.

When this situation became evident, the consultant made his report to the main office. He stated the problem, listed the experiments which had been made, evaluated the test results, and made a definite recommendation for the correction of the mechanism. No reference was made to the source of any of the suggestions. The chief engineers of both plants endorsed the report and the mechanism was soon corrected. The consultant's report gave each of them a source of reference so that neither had to admit the value of the other's suggestion.

One great weakness of a large organization is that so many individuals lose their identity and become little more than a number on a time clock. Attempts are made to counteract this by establishing personnel departments with a director who is supposed to supply the "human touch." Such efforts are largely wasted. This problem of human relations is not one that can be solved by centralized control. It needs more men of good will all through the organization to accomplish anything worth while. Every move that can be made to acknowledge the work of any individual as creative effort will be a move towards better human relations.

For example, some experiments were to be made to determine the influence of different arrangements and different working conditions on certain bench operations performed by girls. Two groups of eight girls each were selected: one group was to work under the changed conditions while the other group was to continue as before so as to give a check, or control, value. The proposed experiment was explained to all at the start, and the results were discussed with them as the tests proceeded.

With the more favorable and more pleasant working conditions, the production showed a marked increase, as had been hoped, but when the conditions were changed back to the original ones, the improved production rate was changed but little. In addition, the control group, working under the original conditions did almost as well as the experimental group working under improved conditions. These experiments are still proceeding. The evidence to date appears to be that the recognition of these operators as individuals, whose efforts are a matter of direct personal interest as well as of importance in the general scheme of things, has aroused their own personal interest in their work and has gained their complete cooperation.

One of the many other possible activities along these same lines is the use and follow-up of suggestions received through suggestion boxes or otherwise. The use of suggestion boxes has been tried in many places, and has generally proved to be of doubtful value. When it fails, it is primarily because of the impersonal operation of the plan. Regardless of the value of any particular suggestion, it should be acknowledged personally by word of mouth by some member of the suggestion committee even before it is considered on its merits. The suggestor should be asked if the interpretation of the suggestion is correct and complete. A brief conversation will make the thought in the suggestor's mind more lucid, and this will enable the committee to consider it more intelligently. When a suggestion leads to experimental work, or is to be adopted, the suggestor should be kept informed of the progress of the project and asked to criticize, correct, or improve the plans. He should be made to feel that it is his own creative effort, and that his opinion is valuable, which it always is.

As one gets acquainted with the individuals in a shop, the feeling of personal responsibility and of pride in achievement shows up in many unexpected places. For example, there is an oiler in one plant who is very proud—and justly so—because in over ten years there has never been a single shutdown on his territory caused by a hot bearing or by lack of correct lubrication.

Business ethics are not defined by any code, and range from the altruistic to the thin edge of the law—or beyond. Nepotism is always a questionable policy, yet it is difficult to condemn any man who wishes to have his son, or an immediate relative, trained to take up his own position when he retires. When this training is received in the same plant where the relative is an executive, one of two conditions will generally result: first, undue favoritism is shown to the understudy by those in authority. Then the relations between the understudy and the rest of the subordinate members of the organization are strained so that he has great difficulty in obtaining the full training and experience which he should receive. Second, in the effort to refrain from showing any favoritism, the executive is unduly hard upon his understudy, who then generally has the sympathy and cooperation of the rest of the organization, but whose attitude towards the work becomes prejudiced. In either case, many able men refuse to continue in an organization where their chances of advancement are limited by the filling of key positions with relatives. When an understudy is to be trained for some relative, it is best to have him receive his training in some other organization, so that he appears on the scene as a

trained and able man, and is able to make his place in the organization on the basis of his abilities.

In a moderately sized and prosperous manufacturing plant, owned by a single family one son and one grandson of the founder were directly connected with the organization. The organization contained several capable men who had worked there for many years, and who were gradually advancing to positions of greater responsibility. During a depression, three additional grandsons whose outside connections had become very unfavorable came into the organization and were given responsible executive positions. As soon as opportunities appeared, four of the ablest of the other men left this organization to take other positions.

On the other hand, there are some organizations where one of the fixed principles is that no son, or relative in some cases, of any executive can hold an executive position. In one such organization, to my knowledge, a son made his father refuse election to the board of directors so as not to jeopardize his own position. In another, a man who was probably the best qualified person, both technically and by previous experience, for an important position was disqualified because his brother was already an executive in another branch.

A very questionable practice is that of executives of one organization owning stock in another which supplies materials, equipment, or services to the first, and using the influence of their positions to steer orders to the outside organization in which they are interested. It is difficult to see much difference between this and the practice of accepting direct commissions for orders placed with suppliers.

A manufacturing plant was having considerable difficulty in meeting the specifications for accuracy of one element of its product. A consultant was asked to assist in running down the difficulty. The investigation showed that inaccuracies in the cutting tools were probably the major cause of the trouble. These tools were standard ones, made in several grades of accuracy. Grade A, for example, was accurate within 0.00025 inch; grade B was accurate within 0.00050 inch; etc.

Incidentally, about a year before, the purchasing agent had been discharged for accepting commissions from some tool salesmen. In order to prevent or minimize the chances of such a practice, the routine was changed so that the tools were not charged to the production department until they were issued for use, and the superintendent of the production department could refuse to accept any tool which was not satisfactory to him. There was a strong suspicion that the commission had been transferred to the shop superintendent.

The new tools when received were sent to the tool crib, and were not

checked until they were issued for service. This inspection was done under the jurisdiction of the shop superintendent. By the time the tools were issued, it was difficult to determine the specific purchase order number under which they were obtained.

The consultant made the suggestion that when new tools were received they should be sent to the inspection bench of the experimental shop which was a part of the engineering department. They would be inspected there, and any tools not meeting the purchase specifications would be returned immediately to the tool manufacturer—before the bill was paid—while all the accepted tools would be sent to the tool crib for issue. The shop superintendent still retained his veto power over the use of any tool.

This suggestion was accepted and the plan was put into effect at once. A week later, about one hundred of the tools in question were received, less than five were passed, and the remainder were shipped back to the maker because they did not meet the purchase specifications. The maker rechecked them and reported that they were within the specifications. Correspondence soon disclosed that although the purchase order given to the tool salesman called for class A tools, the requisition sent by the salesman to his plant called for class B tools. The tool manufacturer fired his salesman and sent class A tools.

The arrangement between the salesman and the shop superintendent was that the company paid for class A tools, the superintendent accepted class B tools, the tool manufacturer received the price of class B tools, while the salesman and the shop superintendent shared the difference. To finish the story—the shop superintendent became disgruntled at the loss of this extra income, which was considerable, and a short time later got into a violent dispute with the general manager of the plant about some other matter. As a result he was fired for insubordination.

Other forms of dishonesty are not unknown in industrial organizations. Payroll padding is not a monopoly of public contracts. The prevalence of such questionable practices is probably no greater here than elsewhere.

Mob psychology also is as prevalent in industrial organizations as elsewhere. The much criticized behavior of legislators when arguing about some controversial subject can be fully matched by a group of engineers trying to reach an agreement on some standard specification for an element about which there is a wide difference of opinion. Some strike disorders are little different from the actions of a lynch mob.

To sum up: the members of an organization are simply people, individuals with their likes and dislikes, hopes and ambitions, characters

and temptations, personalities and abilities. Their creative and productive efforts must be organized under some definite routine if the program of production is to be carried through, but they, themselves, remain individuals and should be treated and respected as such.

Product

The several aspects of the product may be described briefly as follows:

(*a*) *Design.* In essence, this involves the arrangement of the component parts to compose the finished product; the determination of the sizes and forms of these component parts; the choice of suitable materials for each component; and the specification of the number of individual components needed for each assembled mechanism. This work is the responsibility of the preparation group.

(*b*) *Amount and kinds of materials* required to meet a specific production schedule. The rate or amount of production is established by the management. Raw materials must be ordered so that they are available when needed for production. Information as to amounts needed must be furnished to the purchasing department by the production group.

(*c*) The *component parts* must be made. This involves the preparation of production schedules, the planning of the sizes of the lots, the flow of the work through the shop, and the checking of the actual performance of production against the schedules. This is the responsibility of the production group. In addition, the quality of the materials and that of the workmanship must be under adequate control. Part of this may be a responsibility of the production group, but it should be supervised or checked by some authority independent of production.

(*d*) The *finished component parts* must be assembled. This is a responsibility of the production group.

(*e*) The *assembled product* should be tested for performance. This is the responsibility of some authority independent of the production group.

(*f*) *Service* to customers and investigations of the performance of the product in the field may be required. When service is a major item, this may be the responsibility of a separate service group. When investigations of the performance of the product in the field are made, these should be the responsibility of the production design group.

Processes

The many problems of the processes may well be the responsibility of a group of process engineers. Some of these men may be attached

permanently to the preparation group and others to the production group, or again, when preparation activities are few, they could all be attached to the production group, and some of them be loaned to the preparation group when needed there.

Some of the problems are described briefly as follows:

(*a*) *Selection of processes.* The selection of particular processes depends upon the materials used, the design of the component, and the type of the processes available in any plant. The original selection is the responsibility of the preparation group.

(*b*) *Work-holding devices, special cutting tools,* and other *special equipment* must be designed and made to adapt the standard machine equipment to the production of the component parts. At times, complete special machines must be designed and built. This work is the responsibility of the preparation group.

(*c*) The *new equipment* must be set up and adjusted to machine components to their dimensional specifications. The actual set-up may be done by the regular production force, but the preparation group should supervise this work and be responsible for its initial performance. Succeeding set-ups required for subsequent lots are the responsibility of the production group.

(*d*) The *productive equipment* must be operated to produce the component parts according to the current production schedules. This is the responsibility of the production group.

(*e*) The *equipment* must be maintained in proper operating condition. This is the responsibility of the production group.

(*f*) The *search for improvements* in processes should always be a definite objective. This is the responsibility of either the preparation group or a special development group. The full cooperation of the production group is essential here, but the responsibility for such work should be separated from the responsibilities of routine production.

(*g*) Occasions may arise where *new processes* are needed, or where a material improvement in some existing process is necessary. This should be the responsibility of either the preparation group or of a special development group.

Plant

Buildings are necessary to house the personnel, equipment, and the product during the course of its manufacture. The factors introduced by the existence of the plant may be summarized briefly as follows:

(*a*) *Buildings.* Either the buildings already exist or they must be built. Existing buildings often require extensive alterations to adapt them to a specific use. Many items of maintenance must be con-

stantly attended to. Roofs must be tight; broken windows replaced; and sometimes unbroken windows should be washed; walls must be painted, floors must be washed and swept; and every other item of maintenance must be attended to. This work is the responsibility of the plant engineer's group.

(*b*) *Power and light.* Power is required for the machinery and light is needed by the personnel. The plans, installation, and maintenance of all equipment and accessories needed for these purposes is a part of the responsibilities of the plant engineer.

(*c*) *Installation of manufacturing equipment.* The making of plans for the location of the equipment is the responsibility of the preparation group. The actual work of installing this equipment is the responsibility of the plant engineer.

(*d*) *Heating and ventilation.* The making of plans and the installation of all equipment needed for heating and ventilating is the responsibility of the plant engineer. The maintenance of this equipment is also a part of his responsibility.

(*e*) *Sanitation.* The installation and maintenance of all facilities required for the sanitation of the plant is also a part of the responsibility of the plant engineer's group.

(*f*) *Safety.* All problems involved in meeting, and improving upon all legal requirements for safety should be the responsibility of a safety engineer, connected with either the plant engineer's group, the personnel group, or the preparation group.

(*g*) *Materials handling.* The work of installing and maintaining all materials-handling equipment is a responsibility of the plant engineer. This includes both conveyor systems, trucks, and elevators. He may well be responsible for their operation also, and include a traffic group in his organization.

(*h*) *Auxiliary facilities.* Many auxiliary facilities such as compressed air, steam, hot water, and dust-collecting systems are often needed. The installation and operation of all such facilities should be a responsibility of the plant engineer.

(*i*) *Stock rooms.* Many storage spaces are needed in a manufacturing plant such as the raw material stock room, tool cribs in various departments, and finished parts storerooms. The tool cribs and finished parts storeroom are generally operated by the production group. In many ways, the work of the receiving room is closely allied to the work of the purchasing department, whereas that of the shipping room is closely connected to the interests of the sales department. Often, however, these two departments are handled as one unit; the same trucks that bring raw materials from the freight yard will carry the finished

product there for shipment. In such cases, this work may best be placed with that of the plant engineer's group.

Production Control

Production Schedules

The progress of the actual production in the shop may be controlled by one of two methods: first, by what is sometimes known as the stock-chaser method where different men are each responsible for following the progress of a group of parts through the production department. They report progress to a central production office, and bring pressure to bear at any point where a delay has occurred or is in prospect. This method is a simple one and requires the minimum of preliminary planning. The details involved in setting up the special equipment, and the general organization of the productive effort in each department is then a part of the responsibilities of the department foreman. This plan has its merits and its demerits. On the one hand, it is a simple form of organization, the several component parts receive considerable personal attention from the stock chaser responsible for their progress, and usually, the elapsed time required for starting and finishing a specific lot of parts is kept near a minimum. It probably has its greatest value in the production of random lots of different products where the demand is uncertain, or where no general production schedule can be prepared well in advance of the time of actual production. Among its disadvantages are the following: it is not possible to balance the production load effectively by this method, so that at times the demands upon some critical equipment create a local overload. In other words, the actual amount of production from a given plant is less than it could be with more effective planning. This, in turn, generally results in a somewhat higher shop cost of production than might otherwise be necessary. In addition, many conflicts between different stock chasers all wanting to have the use of the same equipment at the same time will occur. This is largely a restatement of part of the difficulty of balancing the production load by this method, but it is also likely to cause antagonism between different members of the same organization.

The second method requires a complete pre-planning of the entire production of the plant, the setting up of definite time schedules for each operation, with the accompanying centralized control of the traffic of all the parts of the products through the entire manufacturing plant. This method is usually followed when the continuous production of a product of stabilized design is involved. It is also followed in many large plants which manufacture a wide variety of products in both large and small lots. The definite time schedules are usually based

upon a standardized basic production schedule which forms part of the specifications or instructions for making a particular product. In addition, this method requires that the general production requirements be established well in advance, so that all the detailed schedules may be made and correlated.

Even when continuous production is involved, it is usually a good practice to break the flow of production into definite and separate lots for purposes of control and accounting. This enables the different production orders to be closed when the lot is completed, the costs to be totaled and analyzed, and it makes possible the early detection of waste or other conditions that tend to increase the shop cost of production.

Some individual stock chasing, or trouble-shooting is generally necessary even when the pre-planning method is used. Unexpected delays are always possible: some critical part of the equipment may break down; some expected material may be delayed in transit from the supplier; material as received may not be adequate and must be replaced; some key operator may be sick or absent with no understudy available to take his place; and so on. Such conditions will upset the original plans so that many temporary changes in the schedules must be carried through in such a way as to cause the least disturbance. To meet emergencies of this sort, individual rather than routine attention must be given. Here the individual efforts and decentralized control of stock chasers will meet the emergency with the least loss of time. The mere adoption of a definite schedule does not insure that it will be followed closely without further attention. All plans and schedules must be constantly checked against actual performance. This needs a continuous follow-up policy.

Material Procurement

The problems involved in the purchasing of material are many and varied. Careful planning, scheduling, and control of the materials procurement can aid greatly in the reduction of the cost of manufacture. In many large plants, the amount of money spent for outside purchases is the largest single item of the cost of production. Excess material on hand is generally a liability rather than an asset. On the other hand, lack of material when it is needed on the production floor will increase the cost of production because of the expense entailed by the presence of idle men and equipment. A thorough organization of the purchasing program coupled with an effective control of production that keeps the product moving steadily and promptly through the plant will reduce the shop inventory of materials in stock and parts in process to a

minimum, and will reduce the amount of working capital tied up in almost frozen assets.

The first step towards an organized purchasing policy is to standardize the purchased materials as much as possible, and to reduce the variety of purchased items to a minimum. Such standardization, as regards the materials used for the product itself, requires the coordinated efforts of the production design group, the production group, and the manufacturers of the materials. It is surprising how great a reduction in variety of sizes and kinds of materials can be made when a wholehearted and cooperative effort is put forth to this end. As far as they may be adequate, standard or stock sizes of the suppliers should be used. This not only reduces their cost but also insures prompt deliveries. When special sizes or kinds of materials are needed, the better the supplier understands these needs, the better will be the service which the customer will receive. The solution of this problem of standardization of materials should be the responsibility of a standards engineer, or group, assisted by the production design group and the production group when their interests are involved, as well as by the manufacturer of the material. All standardization involves many questions of policy, hence the direction or fostering of this work should be a responsibility of the staff of the general management, or policy-making group. Without the interested and continuous support of the general management, most standardization efforts will prove to be inadequate.

A second step towards an effective purchasing policy is to establish a balance between the economical quantities to purchase at one time and the economical size of lot to manufacture. This in turn must be balanced against the normal production schedule. At times, we can afford to pay a little more for the materials and keep smaller the shop inventory of materials and parts in stock and parts in process. Again, the saving in the price of materials may be great enough to cover the increased investment cost of carrying a greater shop inventory. In actual practice, the best solution will be found in the use of both methods. That is, some materials will be bought periodically in such quantities as will match the normal production schedule; other materials will be bought in larger quantities when the stock on hand has reached a predetermined minimum amount, at less frequent intervals. Whatever policy is set up, it should be reviewed at frequent intervals as conditions are subject to change at all unexpected times.

At times, the rising cost of some material may make it advisable to change to some other material. Such changes should not be made, however, without a definite investigation of the actual situation. Conclu-

sions drawn from general averages or statistics are not always valid; there may be some unusual or some overlooked factor present which invalidates the general average. For example, several years ago there was a considerable increase in the market price of copper. A plant which manufactured talking machines used many small parts made of brass castings and others made of cast iron. It had its own brass foundry, and bought its iron castings from an outside foundry. Cast iron is cheaper than brass but costs more to machine.

One of the men in the accounting department suggested that more parts be made of cast iron, in order to reduce the number of brass castings required. He showed by reliable estimates that the increased cost of machining the cast-iron parts would be more than compensated for by the difference in cost of cast iron and brass castings. The general manager, before he acted on this suggestion, sent a young draftsman to see the superintendent of the brass foundry and to ask him how much pig copper he had bought during the last year or two. The manager could have obtained this information over the telephone, but he wished to further the industrial education of the young draftsman.

When the foundry superintendent heard the question, he laughed, took the young man outside and showed him a pile of several tons of pig copper, covered with dust, which was stacked against the outside of the building. He said that all that pig copper was there when he first came on the job some years before, and that he had never used or bought a single pig. He explained that he obtained more than enough material for his foundry from the scrap from brass punchings—sheet-brass parts that could not be altered to sheet-steel ones—and from brass chips which came from the machining of brass castings and brass rods. For virgin copper, he used the trimmings from the matrices of the records which were made by copper plating the wax master records. The excess of all this material he was selling as scrap metal.

On receipt of this information, the manager had new estimates made. The result was that some cast-iron parts were changed to brass castings because this scrap was worth more to the company in the form of brass castings than it was worth as scrap metal. In addition, all the stored copper pigs were sold while the price of copper was high.

The responsibility of determining the purchasing policy as regards the quantities to order might well be given to the purchasing department, assisted by information and advice from the production design group, the production group, and the accounting department. The probable volume of sales in the immediate future should also be con-

sidered here. The selection of the specific materials to be used in the product is the responsibility of the production design group.

A third step towards an effective purchasing policy is to search out suitable sources of supply. It is advisable to have more than one source of supply for any given item whenever possible. When several sources of supply are available, each of them should be graded according to their prices, reliability, promptness in shipping orders, and the quality of their product. Price alone should never be the guide to the selection of a supplier. From definite records of the length of time between the sending of an order for a specific item and its actual receipt at the plant, an average should be established. This information is essential and makes possible the making of a definite time schedule for purchasing.

In one well-organized plant, the purchasing schedule is so arranged in relation to the average length of time between issuing a purchase order and receiving the material that no appreciable amount of material is received more than about twenty-four hours before it is needed on the production floor. This policy has reduced the shop inventory to a remarkable amount, and is one of many other factors that make for a low cost of production here. When the general manager of this plant was asked if any materials were ever late in arriving, he admitted that this happened occasionally, but had not yet resulted in any delays in the completion of the finished product. To accomplish this, the production departments had to spurt for a short time to make up for the delay. These occasional spurts made a break in the regular routine, and the production force took pride in meeting the challenge and in maintaining their production record. This manager was one who was in close personal touch with the personnel of the shop, and he said that he knew of no complaints or objections to the practice. He felt that these spurts helped to keep the shop on its toes. Occasional breaks in a regular routine are often welcome and beneficial.

The responsibility of finding sources of supply and of determining the average length of time between the placing of an order and the receipt of the material belongs with the purchasing department. The policy to be followed in setting up a time schedule in relation to the receipt of material and its need on the production floor is one to be established by the general management.

One further step is needed to complete an effective purchasing policy. Materials should be ordered to definite specifications. The material, when received, should be checked against these specifications. One action without the other is useless. Although most suppliers are responsible parties—they must be if they are to remain in business

for any length of time—mistakes and oversights will occur. And strangely enough, these mistakes occur more frequently with purchasers who do not check their materials against the specifications than with those who do. A purchaser who maintains a definite material checking or testing policy has fewer controversies with his suppliers than one who has no such consistent policy. This is probably due to the fact that when a definite testing policy is followed, the purchase specifications are more definite so that the supplier has a better understanding of the needs and wants of the customer than he would have without this definite information.

As an example: a company was having trouble with a varnish finish which was applied over an enameled base on his product. The varnish did not dry properly and lacked luster. The finger of suspicion pointed to the spirits of turpentine, a new supply of which had recently been received. A sample of this turpentine was sent to a chemical laboratory for a simple analysis. The test consisted of fractional distillation with a rise in temperature check on the fractional distillates. The results of these tests were compared with similar ones made at the Bureau of Standards on spirits of turpentine and other petroleum substitutes. The comparison indicated the presence of less than twenty-five per cent of spirits of turpentine, while the remainder checked closely in its behavior to these tests with one of the petroleum substitutes.

The supplier was notified of the results, and was indignant. He asked for a sample for testing in his own laboratory. The next word received from him was that a new supply was on the way, and that the previous shipment should be returned. An unfortunate mistake had been made in his shipping department, for which he must apologize. A sample of the new shipment was tested and found to agree in its behavior with that of spirits of turpentine. Incidentally, the difficulties in the behavior of the varnish also disappeared.

The making of the purchase specifications should be a responsibility of the standards engineer or department. In the absence of any organized standardization activities, this would be the responsibility of the production design group. The testing of materials should be the responsibility of the inspection or quality control group, which should be entirely distinct and independent of the production group.

Routine Set-Up

When different products are produced on the same machine equipment, the special tool equipment used must be removed and stored until it is needed again, after a definite lot of one product has been completed. Then the equipment for the next product must be col-

lected from the tool storeroom, set up on the machine-tool equipment, adjusted, and operated. This work must be done machine by machine. Thus when several machining operations are required on a single part, the equipment for the first operation will be torn down and the equipment for an operation on another part set up while the rest of the equipment for the first part is still at work completing the operations on that part. In order to reduce the idle time of the machine-tool equipment to a minimum during these transition periods, careful planning and suitable schedules are required.

Detailed instruction sheets for each operation are usually made out and kept on file for use when they are needed. The instruction sheets list all the special equipment and all the cutting tools and gages required, often indicate the location of this special equipment in the tool storerooms, specify the speeds and feeds that are to be used—often by specifying the actual change gears to be used—and include any special or general instruction that may be necessary. The more detailed and specific these instruction sheets are, the less will be the amount of information that must be remembered by the set-up crew, and the less will be the chances of making mistakes because of oversights. No plans or instructions are ever completely foolproof. Every effort should be made to include as much detailed information as possible so as to reduce to a minimum the chances of making mistakes. If mistakes are made, however, the instructions should be revised or extended so that these particular mistakes or oversights will not be made again.

The actual change-over or set-up may be made by the machine operator or a machine adjuster who is in charge of a group of machines, or by a special set-up crew, the choice depending on the general organization of the production department and the skill and responsibility of the operator, but the machine operator should always be allowed to assist in this set-up when he appears interested, since it gives him the opportunity to increase his knowledge and skill.

The actual set-up consists of mounting the special equipment and cutting tools on the machine tool, and of adjusting their relative positions until after a series of trial cuts, the equipment will machine the part to the dimensional specifications and to the surface finish conditions required. These routine set-ups are the responsibility of the department foremen.

Tool Standardization and Storage

The possibility of complete standardization of cutting tools depends on the standardization of the elementary surfaces of the component

parts of the product and on the standardization of those elements of the machine tools to which the cutting tools are attached. The major advantages of the standardization of cutting tools are the reduction of variety and sizes, the potential reduction of the inventory of tools in stock, and the possibility of securing standard tools from the stock of the small tool manufacturer at short notice. In addition, the actual cost of standard cutting tools will be materially less than the cost of special tools. These standardization activities should be instigated and followed through by the standards engineer.

Tool cribs for the storage of the cutting tools are usually provided for each different manufacturing department, and carry a stock of the cutting tools used in that department. Special cutting tools when not in use are often stored in a separate tool storage room with the other special tools and fixtures needed for a particular operation. When another lot of parts is to be machined, and these tools are removed from storage, it is usual to transfer spare special cutting tools to the tool crib for issue when needed. Frequently a tool-sharpening room is operated in connection with the tool crib, and duplicates of special cutting tools are carried, so that while one tool is being sharpened, another is available for use. The practice is often followed that any cutting tool returned to the tool crib is resharpened before it is stored, so that it is ready for reissue whenever it is stored in the tool crib. These tool cribs are usually under the jurisdiction of the department foreman.

Replacement of Cutting Tools

Records should be kept to establish the normal life of cutting tools so that replacement tools can be ordered in time when they are needed. When standard tools are used, the production group should determine the minimum number to have in stock and the re-order quantity. For special cutting tools, if they are made in the plant, the order for replacement should be issued early enough so that they can be carried through the tool room as a routine job. When they are made outside, the order should be also issued early enough to prevent any delay in the production schedule. The amount of money tied up in the inventory of cutting tools is much less than that which may be tied up in raw materials, and the absence of a cutting tool at a critical time will delay production, so that the margin between the issuing of an order for cutting tools and their need in the shop should be much greater than the margin for ordering the raw materials. When a card record of the cutting tools is kept, all information about re-orders should appear on the card. When a special cutting tool breaks unexpectedly,

and there is no replacement tool on hand, a critical emergency is created. A few such emergencies would justify the existence of an emergency tool room. Whether or not records about the life of cutting tools are kept, the department foreman who uses them is responsible for making his requisitions for new cutting tools, particularly the special cutting tools, early enough to avoid delays.

Production Records

Much bookkeeping is necessary for adequate control of production. Records must be kept of the amount of material requisitioned for the component parts of the product. The amount of time spent by the production force on each operation on each component part, as well as the number of parts processed, should also be a matter of record. These records should also include the amount of spoiled work. They are needed to check the progress of any given lot or order through the production department and the cost of production. The earlier this information is available, the earlier can steps be taken to correct conditions which increase the cost of production or to relieve conditions that delay progress.

The time and cost department keeps these records. Much of this information is needed by the payroll section. It is also available to the production department. The shop records, from which the time and cost records are derived, are often made by a clerical force in the production department. These shop clerks may be an integral part of the time and cost department, or may be part of the production department to which they are attached.

Stock Records

Besides making enough parts to meet the current needs of the assembling department, it is often necessary to make additional quantities of some parts to meet the demand for replacement parts. When a change, made on some component part, is such that the new part cannot be substituted for the old one, the production group must determine the number of old parts to be kept in stock for use as replacements. Occasions arise when a special lot of obsolete parts must be made to meet the demand for replacement parts on an old and obsolete product. The quantity of replacement parts which should be made in addition to parts for assembly can be determined from past experience and statistics of past demand. These quantities should be included in the regular production schedule. A perplexing question about these replacement parts is the length of time that they should be carried in stock, after the manufacture of a given item has been

discontinued. Many machine tool manufacturers have received complaints from old customers because replacement parts were not available from stock for machines which had been sold fifty years ago. Some companies make a practice of sending to the customer blueprints of such obsolete parts which are not in stock, and suggest that they make them themselves or have them made locally.

When there are complete records of the number of parts completed, their disposition, and the number remaining in stock, the number of parts sent out for replacement purposes can be readily determined.

Some small parts, made on punch presses, screw machines, and other automatic equipment, are machined in periodical lots, even though the production of most of the component parts is continuous and adjusted to the rate of assembly. For such parts, a minimum amount of stock is established, as well as the size of the manufacturing lots. When the amount of stock is reduced to the minimum, a requisition is made almost automatically for the production of a new lot. The keeping of all the stock records needed for these various purposes is a duty of the shop clerical force.

Materials Handling

The details of the problems of materials handling depend upon the nature and size of the component parts of the product and the factory layout of the productive equipment. These problems range from the handling of parts of almost microscopic size in a watch factory, where a thimble will hold a day's production from several automatic machines, to those where the product is so massive that portable power tools are brought to the work and set up there to perform specific machining operations.

When the parts of the product are small, they are usually handled in tote boxes from operation to operation. When the machines performing the succeeding operations are near the machines performing the preceding operations, these tote boxes are usually carried by hand from one group of machines to the other, but when the machines are at a greater distance from each other, the tote boxes are carried on trucks, some drawn by hand and others driven by mechanical power. When the volume of production is moderate, this traffic requires little planning, but for large volume the traffic problem may become so acute, that it may often be necessary to relocate the equipment.

For example, a plant making sporting rifles and shotguns in comparatively small lots and of several different models, had the equipment in their barrel shop arranged with the different types of manufacturing equipment grouped together. This shop had three floors and

a single elevator at one end of the building. In the course of manufacture, different designs of barrels might take somewhat different routes through the shop, but they all went up and down the elevator several times before they were finished. When the entire production of the plant was devoted to making one single type of military rifle, the rate of production in the barrel shop was restricted by the traffic jam at the elevator to less than the productive capacity of the machine tool equipment. As a result, a new factory layout was made for the barrel shop so that the machines needed for the successive operations were placed adjacent to each other. This allowed the barrels to travel in a continuous path from start to finish, and completely eliminated the traffic jam at the elevator.

The responsibility of operating all this trucking traffic may well be given to the plant engineer, or it may be organized as a traffic division of the production department. It does not belong to any single manufacturing division because a large part of the traffic is between different manufacturing and other divisions.

With large and heavy component parts, particularly when the rate of production is large and continuous, special conveyor systems are generally installed to carry the parts from machine to machine, and from one department to another. Some of these are driven by power and others are operated by hand. In addition, many power-lifting and handling devices are provided at particular machines to lift heavy parts into position and to remove them when the work is completed.

In plants where the work is large and heavy, and the quantities are small or varied in character, many types of traveling cranes, overhead rail hoists, and other mechanical lifting devices of many kinds are used for moving, setting, and removing the work.

Another phase of the materials-handling problem is that of operating the receiving and shipping department. In many plants, these two duties are combined. The raw materials and other incoming shipments must be handled and sometimes stored until they are needed. The finished product must be packed and shipped. Whether this is handled to and from the shop in trucks or from a private railroad siding built to the plant, the same equipment is generally used for both purposes. This work is a general service to the plant, and would appear to be a logical part of the plant engineering department's duties.

It is not easy to make exact schedules for the changing and varying detail of the work in the receiving and shipping room, particularly in a plant making a wide variety of products and shipping to many different customers. In one such plant, the general manager became much disturbed because of the large number of orders which were shipped

late. An investigation indicated that most of these late shipments were only about one day late, but they upset the customers' time schedules and resulted in complaints from them. After some thought, he decided to try the effects of a special group bonus plan for the shipping crew, including the truckmen. He used the percentage of late orders for the previous month as a basis, and offered a special bonus for a reduction of this percentage. Its effect was almost instantaneous and very gratifying. The percentage of late shipments was reduced materially, and this record was maintained.

A copy of every customer's order, giving the shipping instructions and promised date of shipment, was sent to the shipping room as a matter of routine. The shipping crew would arrange these orders according to the promised date of shipment. Early each day, they would take the shipments for that day, check off those that had already been received in the shipping room, and start out into the shop to find the others. They were in effect an additional corps of stock chasers, and they threatened dire happenings if the material was not finished and sent to them in time. On delayed orders, they would truck the work to the shipping room themselves. The truckmen would wait a little overtime, if necessary, to take the last material boxed or shipped. The insistence of the members of the shipping crew appeared to be more potent with the production force than any pressure which the production manager could bring to bear.

Maintenance and Repairs

All productive equipment in use must be maintained in proper operating condition, and be repaired when necessary. This requires some force of skilled mechanics. Machines, cutting tools, work-holding devices, and gages wear in service. Plans must be made for the replacement of expendable tools, such as cutting tools and gages, and these needs may be supplied principally by outside sources. Major repairs to machines can often be made best by the manufacturer of the equipment. In fact, it would be a good plan periodically to send the machine tool equipment back to its manufacturer for overhauling and sometimes for rebuilding. These are items of maintenance that can be definitely planned for in advance.

Emergencies, however, always arise at the most inopportune moments. To meet them, some maintenance department or emergency tool room is necessary. Promptly and effectively to meet such emergencies as broken tools, excessive wear on work-holding devices, delayed completion of some urgently needed new equipment, and machine breakdowns, the number of men and amount of tool room equipment

must be greater than that which would be needed to do this work if it could be scheduled over a period of time. Yet it would be disastrous to depend entirely upon outside help to meet all emergencies. It is wise to organize an emergency machine shop and tool room sufficiently extensive to meet the average emergency and to plan to have this department make a certain amount of the expendable tools or new tools to keep the force busy between emergencies.

The responsibility for reporting the need of repairs or the need for correction of the manufacturing equipment belongs to the department foreman where the equipment is used. The responsibility for having these repairs made rests with the production department. The emergency machine shop and tool room should therefore be an integral part of the production department.

CHAPTER VII

SELECTION, TRAINING, AND DIRECTION OF OPERATORS

Modern production methods are a direct outgrowth of the development of methods for producing interchangeable parts. The original idea was to develop or to create manufacturing processes which could make the component parts so nearly identical in size and form that they could be assembled without fitting, and that they could be interchanged from one mechanism to another similar one without special fitting. This would secure the economies resulting from the elimination of the slow and expensive fitting at assembly as well as the convenience and utility of rapid repair by the substitution of spare parts for worn or broken ones. The plan was first proposed some time before the Revolutionary War for the manufacture of muskets, and one important argument in its favor was the convenience and utility of quick repairs in the field by the substitution of parts, so that from a dozen damaged muskets, eight or ten good ones might be re-assembled.

Nearly a century passed before any reasonably close approach to success was reached. Early attempts showed the need of many new manufacturing processes, which would transfer much of the skill of the craftsman to the manufacturing equipment. Very early it became evident that a closer approach to identity among similar parts could be obtained by mechanical means than by manual skill. During the period of this development, many of the modern manufacturing processes had their genesis.

The first reasonably close approach to successful manufacturing of interchangeable parts was made in the production of firearms. Many of the anticipated benefits of this method were realized: economy of assembly and facility of repair. In addition, once the special equipment had been made and set up, there appeared an entirely unanticipated economy in the production of the component parts themselves. Thus with lower costs of production, and consequently a lower sales price for the product, the potential market was greatly increased, and this in turn led to a greater volume of production, so that today, the emphasis has been shifted to mass production with interchangeability as an accompanying feature.

The transfer of skill from the workman to the equipment has been

reached by breaking down into simple tasks for the operator the productive effort and manufacturing operations on each individual component part, and by building into the equipment as much as possible of the skill and technique formerly contributed by the craftsman. Much automatic and semi-automatic equipment has been developed to the point where the task of the operator is simply to insert the raw material and to remove the finished work. However, a high degree of skill is still required of the mechanics who make the equipment, adjust it, and keep it in a satisfactory operating condition, and a large degree of integrity is still required of the machine operator who must make sure that the work-holding device is properly cleaned, that the unfinished part is properly seated and locked in position, and that the cutting tools are still sharp and working properly. In addition, there still remain many processes where definite skill and technique, as well as integrity, are required of the operator if he is to get satisfactory results.

Quoting from one of Walter Bagehot's economic studies, entitled *Cost of Production,* we have this comment on labor and skill:

> Labour—the muscular and mental force of man—is a main element in almost all kinds of production, and the principal one in many. But we must be careful not to imagine that this labour which the capitalist purchases is one thing. It is hardly even one *kind* of thing. The labour of a ploughman is distinct from that of a clerk; that of a clerk from that of an engine-driver; that of an engine-driver from that of a cabinet-maker; and so on without end. The difference between these various kinds of labour is in a great degree the consequence of acquired habit. Each man is trained in his department, and in it, therefore, he acquires a skill. These various kinds of training go down to very low degrees—to the "navvy," who just knows how to dig out plain earth—and runs up to the most accomplished artisan—the maker of astronomical instruments (say) who can turn out work of the finest and most minute accuracy, and to a great extent knows how he does it, and how that accuracy is acquired. There is a common coarse sort of human nature which can be taken a certain way in any pursuit, but which will not go very far; and over and above that, there is a finer element which can only be taken in one direction, or some few directions for which it has an affinity, and which is often accompanied by an incompetence to go even the first step in many others. Out of these natures specifically inclined to it, each trade gets its best labourers.

It should be evident that a wide variety of degrees of skill and ranges of skill are needed on the production floor. These range from the simplest operations where a new workman may be instructed in the rudiments of his task in, say, half an hour, and attain proficiency

in a few weeks, to a skilled machine adjuster or operator who has spent years in training and developing his skill. The selection of individuals for specific tasks is the responsibility of the department foreman or superintendent, but in order to make these selections intelligently, he must have some knowledge of the skill, character, and capabilities of the individuals.

Operators of Automatic Machines

The operators of automatic manufacturing equipment are sometimes responsible for its set-up and maintenance as well as for the insertion of the raw materials and the removal of the finished parts. Frequently one operator is in charge of several automatic machines. These men are highly skilled specialists who may be recruited from the ranks of skilled mechanics or who may start as helpers, and acquire their training during several years of experience in this work. Many of these operators are paid on the basis of piecework or on an individual bonus system.

Some years ago, the general manager of a large plant making upset steel products was passing through the cold-header department of his plant. Here were some thirty upsetting machines operated by five men, each of whom had charge of six machines. All this work was on an individual bonus plan. He noticed that one man was busy setting up or adjusting one of his machines, two others were idle while waiting for attention, and the other three machines were running normally. The four other operators were sitting down, reading papers, with an occasional glance at their machines, all of which were operating. He said nothing to them, but when he got back to his office, he began to ponder over the situation. Finally he decided that it might be a good plan to put the whole group of five men on a group bonus plan.

The next day, he went out to the department to discuss this matter of a group bonus with the men. They were not enthusiastic, but finally agreed to try it for a time, with the promise that regardless of how it worked out they would receive not less than their average pay for the past month, and that after a period of three or four months, the payment would be on the basis of group bonus or individual bonus as before, depending upon the wishes of the operators.

Two or three weeks later, the general manager was passing through this department again. One machine of the thirty was stopped for setting-up on a new job. All five men were working together to get the machine going—the man whose machine was involved was directing the work. Nothing had been said to them about helping each

other. At the end of the trial period, all the men were enthusiastic about the group bonus, so it was retained.

In other cases, the task of the operator of semi-automatic and full-automatic equipment is to remove the finished work, load the fixture with the raw material, and start the machine in operation again. These men may tend from one to several machines, depending upon the relative length of time required for the loading operation and the length of time of the machine cutting cycle. These operators, between loading cycles, sometimes burr their finished work with a file at a bench. It is a common practice to require the man who makes a burr to remove it. Under such conditions of operation, a machine adjuster, who often acts also as a sub-foreman, has charge of setting up and adjusting the machines of several operators. Sometimes he is responsible for the resharpening of the cutting tools, but this is generally done by a tool-sharpening group. Often he also acts as a floor or process inspector and gages the work produced by his group of machines. He is responsible for instructing new operators who may be assigned to the machines which are under his care. It is evident that the degree and range of his skill are much greater than that required by the machine operator. Many of these machine adjusters are trained from machine operators who show an aptitude and liking for this type of work.

Operators of Manually Controlled Equipment

Manually controlled operations range from those of which the rudiments may be learned with a few hours of instruction and in which proficiency may be attained in a few weeks' experience to others which need months of preliminary instruction and a year or more of experience for proficiency. This work is often on a piecework or individual bonus payment basis. When the combined efforts of a group are needed, a group bonus plan is sometimes used. In one large plant where considerable work is done on group bonus plans, the groups or teams are arranged according to the wishes of the particular groups. Sometimes one member refuses to cooperate and thus holds back the amount of production of the group. Then the lagging member is transferred to some other work where group effort is not involved, and a new man is substituted.

One great difficulty of all wage incentive plans, particularly when manually controlled operations are involved, is in making a correct start. On new work, no matter how similar to a previous operation it may appear to be, the basis of payment must be established from some estimate. Although the average for a large group of operations

will generally be accurate, some individual operations will be over-estimated while others will be under-estimated. The general practice is to guarantee that no rates will be reduced—for a certain time period at least—unless a change is made in the operation. This clause has often been much abused in the past. A nominal change that makes no material difference to the particular task will be made in the equipment for an operation whose rate is manifestly too high, and the rate will be reduced because of the change in the operation.

With some inevitable inequalities in the rates as they are originally set, this condition should be frankly recognized. Some provision for adjustment should be arranged at the start, instead of guaranteed rates for all operations. However, it should be a basic principle that any reduction in the rate for one task on any given job should be balanced by equivalent increases on other tasks whose rates are too low. Nevertheless changes should not be made until after conferences are held and agreements reached with the individual workmen. In the event of objections by any individual to a reduction of rate, he should be transferred to one of the operations where the rate appears to be too low. The amount of pay which one individual is earning on any piecework rates should never be taken as conclusive evidence that the rate is too high. It may well be that the workman is above the average in application and ability, and truly earns all he receives. Instead of raising questions about the possible revision of rates as soon as any one operator gets a large pay check, it is a good plan to transfer him to some other operation that may appear to have a normal or low rate. If his earnings there are larger than those of his predecessors, it is strong evidence that it is the man and not the rate that is above the average. Once a group of workmen is fully convinced that an honest effort is being made to adjust all rates to an equitable basis, and that the move is not designed to reduce costs at the expense of the operators, such a plan will prove effective.

On many operations where finger dexterity, constant attention to detail, and neatness are necessary, girls usually prove to be more satisfactory operators than men. This holds true for many other operations which require no great physical effort but do require strict attention to the task in hand. For example, in one factory, girls were used as messengers instead of office boys because they were more expeditious and were not distracted while on an errand in the shop by operators and processes that often proved to be fascinating to boys.

It is difficult, at times, to appreciate fully the degree of skill, or amount of natural aptitude needed in the operator on some new operation. If, by chance, the first operator chosen takes hold of the work

and soon becomes proficient at it, the assumption is made that it is not a critical task. It is only when the original operator is lost, and great difficulty is experienced in trying to train a successor, that some of the intrinsic difficulties become evident. In the manufacture of some counters, a small glass window was cemented in the case as a window for the number wheels. These were made of window glass. Two special frames were made to locate straightedges in the correct positions while the glass was being cut. The glass was cut or scratched on one side in one direction, which would divide it into strips, and then turned over and cut on the opposite side in a direction at right angles to the first scratches, to divide the strips into individual windows.

The first girl selected for the glass-cutting work soon became proficient, so that no further thought was given to it until after a few years the girl planned to be married. About a week or so before she was to leave, a new operator was selected, and the original operator tried to teach her, but without success. Several other girls were tried, with the same results. Before a new operator could be trained, the original operator left. When continued attempts to find an operator with a natural aptitude for cutting glass cleanly proved fruitless, it was decided to design and make a glass-cutting device which would not require this skill on the part of the operator. This took time, but eventually it was accomplished. In the meantime, the stock of cut glass was used up, and the assembly of counters was at a standstill. The original operator was persuaded to come in for a couple days a week until the new equipment was completed. Incidentally, this operator was cheerfully paid her former week's wage for her two days' work.

Analysis of Process and Operator

More attention than is ordinarily given should be devoted to a careful analysis of the different types of processes and of the characteristics of the operators best adapted to their control. This should include a study of the actual degree of accuracy attained in production by the different processes and of the degree of skill and care required to obtain specific results. In addition, certain statistical information can be collected and arranged which will be of great value in making more accurate schedules and forecasts of actual production.

For example, the perfect performance of any operation will give a certain output in a given time. The actual output is always less than this perfect score because of many variables. A statistical average for this actual output as compared with the full potential output is necessary for the purposes of estimating, production planning, and indica-

tion of conditions that may need investigation and correction. Among the many elements of delay are the following:

(*a*) *Absences of operators.* If a record is kept of the absences of operators, from all causes, segregated by departments and processes in that department, a percentage value can be established which will give a close measure of the amount of time and production that may be lost because of this factor.

In one large plant where such records are kept, the percentage of lost production from this cause ranges from three to five per cent.

(*b*) *Training new operators.* From both records and an actual survey of operating conditions, the following values may be obtained:

(1) The length of the average period of employment of operators on specific types of processes. This value is affected both by the ending of employment of operators with the plant and the transfer of operators to other tasks.

(2) The average length of time required for a new operator to attain proficiency at his task, and the operator's effectiveness or efficiency during the training period.

From these values, the average percentage loss of production based on the entire average length of employment can be determined. This value may range from one to five per cent.

In times of normal operation, these average values are adequate. When, however, a radical change in production is involved, or a greatly increased volume of production must be obtained—and most of all the operators are in training at the same time—then the production loss in the starting months of the production is much greater. Such values should be based upon the new operator's efficiency during his training period.

(*c*) *Repairs to equipment.* If records are kept of the amount of time spent on repairs to the equipment of the different sizes and types, a percentage value of the production lost by this cause may be readily established. This value would be about one per cent and up, depending upon the ruggedness of the equipment and the severity of the work accomplished by it. A material difference may exist in this value between new and old equipment. Such values would also be a valuable guide to a choice between similar equipment of different manufacturers.

(*d*) *Set-ups.* The percentage loss of production from this cause will range from nearly zero on equipment which is set up for long periods of time for the continuous production of a stabilized product to an appreciable amount on equipment used for short runs on small lots of

a varied production. The average amount of time used to set up any type of equipment is a value needed in determining the economical size of lot to make. This value is also needed to determine the elapsed time required to start the production of a new commodity.

(*e*) *Tool sharpening and re-adjustment.* Cutting tools become dull and must be replaced with resharpened ones, or the equipment may be stopped while the tool is being resharpened, if a duplicate cutter is not available. Frequently the machine must be re-adjusted to produce work of the correct size with the different cutting tool, or because the adjustment of some element of the machine has changed under the stress of the cutting operation. The smaller the tolerances specified, or the smoother the surface required, the more attention must be given to these duties. This is one of many elements of the increased cost of extremely accurate work. Records should be kept of the frequency of stops for changing the cutting tools and for re-adjustment, as well as of the amount of time consumed by these tasks. From these, an average percentage value of production lost because of this element may be established. This value will vary from about one per cent on simple processes producing work to a normal degree of accuracy up to possibly fifty per cent on more complex processes where the work must be held to an extremely close degree of accuracy.

(*f*) *Miscellaneous items.* Many miscellaneous items of lost time must also be considered. Unexpected interruptions to the flow of parts in production are always possible. Operators take time out for medical attention and treatment of minor cuts and scratches and for attention to personal needs. Supervisors occasionally take some of the operators' time when seeking information of various kinds, and so on.

By adding all the normal losses together, we obtain a value of from about ten per cent to sometimes over fifty per cent of production lost by all these many items. Average values for all the principal processes should be established for the use of the planning and scheduling groups.

In addition to the percentage of production normally lost on the different processes, and in connection with them, a study should be made to determine the degree of accuracy normally attained under various conditions of operation. This should be in addition to any inspection of parts in process which checks the performance of the processes against the dimensional specifications. This is information urgently needed by the makers of the production design. Too often the available information of this nature represents hopes and opinions rather than definite knowledge. A series of actual measurements should be made from time to time to determine these values.

For example, an estimator was called upon to determine the cost of some work for an outside customer. This work included several milling cuts which were given a tolerance of one thousandth of an inch. The estimator, who was personally acquainted with milling operations and with the elusiveness of a single thousandth of an inch, included three milling operations for each cut: a roughing, a finishing, and a qualifying milling cut. The estimated cost of the qualifying cut was greater than the combined cost of roughing and finishing. The shop superintendent objected, and claimed that two cuts at most were enough, and that the roughing cut as well could possibly be eliminated. He claimed that a tolerance of one thousandth of an inch was normal for milling, and the foreman of the milling department supported him. As they were unable to convince the estimator, an actual test was made on some parts then going through the milling department. These were small steel parts, with no cut longer than about four inches, which were being machined on semi-automatic milling machines. Several hundred measurements were made, with about the following results:

Type of Cut	Variation in Size
Single milling cut, ordinary care	0.008 inch
Single milling cut, with slightly more care	0.006 inch
Second cut, with care	0.004 inch

If a smaller tolerance than any of the foregoing must be met, consideration should be given to some other process than milling to accomplish the task.

At the same time, a study should be made of the degree of skill and of the most important characteristics needed in the operators of the different processes. These studies would form the basis for the selection of individuals to be assigned to specific tasks.

All these studies and analyses are the responsibility of the process engineer. He must know not only the technical features of the special processes for which he is responsible, but also the human factors of their operation.

Selection of Men for Further Training

Many factors are involved in the problems created by the personnel. Most of them can be handled best by a personnel department responsible to the general management. Among the agencies to take care of these factors we have the employment office with its records, and the payroll department with its records of attendance and of the production achievement of the individuals. To these may be added a per-

sonnel records office where individual cards or files for each individual should be kept. An attempt should be made to appraise the ability, training, reliability, and potential value of each individual. Such records are an invaluable aid when selecting men for advancement or for further training. Before any definite action is taken in regard to any person, however, some one in responsible charge should personally check this man's record. Much of the information on these records, particularly that which appraises the general value of the individual, comes from the foreman and other immediate supervisors of the individual. Most of this information should be reasonably reliable, but these superiors are human and, at times, the appraisal is based on their personal prejudices regarding the individual rather than on his intrinsic ability and worth. Some foremen are definitely afraid of any of their subordinates who have more ability than they themselves. As a result, their reports on these individuals for the personnel records are anything but accurate. On the other hand, many such subordinates have more ability than diplomacy and in their efforts to make suggestions for improvements and for economy, they seem to be criticizing the knowledge, ability, or judgment of the supervisor. This has unfortunate results.

Every individual should have access to his own personnel record. If he believes that it is incorrect or incomplete, he should have the right of appeal. Such appeals should receive serious consideration, and the records in question should be carefully checked by some one in responsible charge, but not by the individual's immediate supervisors. The factory manager and the general manager of the plant could well afford to budget a definite amount of their own time for checking and investigating some of these personnel records. Incidentally, by this means they will be in a position to add much to the personnel records of the foremen and other supervisors. These records should include those of all individuals in all branches of the organization, from the sweepers, janitors, and laborers to the general manager himself.

General classifications of the characteristics of individuals are always incomplete, indefinite to a large degree, and often dangerous. Furthermore, there are so many different ways in which these characteristics may be classified that the method selected is always open to criticism. With these reservations individuals may be divided into two general groups: first, those who are individualists or who can work best by themselves; and second, those who are gregarious or who can work best with a group or crowd. To be more technical, persons in the first group are said to have subjective personalities, whereas those in the second group are said to have objective personalities. One great prob-

lem of selecting individuals for specific tasks is to assign, as far as possible, those with subjective personalities to tasks which do not depend upon continuous group effort, and to assign those with objective personalities to the work that needs concerted group effort. There is need for both types, and this characteristic alone does not give a measure of the true value of any individual to any organization.

A definite policy should be adopted to train every individual who shows promise and thus to increase his skill and usefulness to himself and to the organization. An industrial plant should be not only a manufacturing organization but also an educational institution. Some of this training may be by groups or organized classes, although much of it should be individual in character. The larger part of the organized personnel activities of any plant could be profitably devoted to this end. This is not an altruistic or benevolent move, but is one which can be carried through as a definite profit-making activity. One of the largest fields for the reduction of cost of production in almost any manufacturing plant is the reduction of scrap and waste in industry. Effective reduction of waste, which also includes the cost of making mistakes, demands the cooperative efforts of every individual in the organization. The better the training and the higher the skill of each worker, the more effectively this task of reducing waste will be accomplished.

It is sometimes worth while to spend some money in letting a man make a mistake. If he can learn by experience, he will be a better man because of it. If he cannot learn by experience, but is governed by his emotions, the sooner it is known, the better. As an example: a new foreman from outside a certain plant came on the job at the time that a radically new unit was to be built and tested in his department. Both the design and the materials selected for some of the component parts were radical departures from conventional practice. This foreman took exception to the plans and claimed that the success of the project was hopeless from the start. He was certain that the only successful plan was to adhere to the conventional design and materials, even though the conditions of operation for this unit were far more severe than on any similar mechanism which was known.

This design had been developed with the cooperation of an outside consultant to whom the objections of the new foreman were reported and he was asked to advise on the subject. He advised as follows: first, more than half the chances of success would be lost if the foreman in charge had strong doubts of ultimate success or was antagonistic to the program; second, it was possible, but hardly probable, that the conventional design and materials would work; third, if the fore-

man could learn by experience, he would be a more valuable man if his own suggestion was tried first—if it failed and the other design proved to be adequate, the experience was worth the few hundreds of dollars it would cost; fourth, if he could not learn, the sooner this was known and the sooner he was replaced, the better. To the management, this last information would be well worth the cost of the experiment.

After some hesitation, this advice was followed. The conventional design was tried and it failed completely. Then the reasons for the departure from the conventional were carefully explained to the foreman. He might not have appreciated them before the test, but he was very much interested then. The new unit was made and tested. It proved to be entirely adequate, and the foreman was as pleased as anyone else. Incidentally, this episode improved the relations between his department and the engineering department, and the foreman is now one of the men in the plant most cooperative with the engineering department, both on problems of current production and on the manufacturing development of new products.

Another incident relates to the selection of a young man for further training. He was operating a drill press equipped for tapping special nuts. This drill press was equipped with an automatic dial feed for feeding, positioning, and holding the nuts during the tapping operation. The operator fed the drill spindle manually as the nut came into the tapping position. He noticed that one arm of the indexing mechanism was in timed relation with his manual operation. He then tied a cord from the spindle handle to this oscillating arm, after which he sat on his stool and watched the machine do all the work.

The manager of the plant, passing through the department, noticed his contrivance and sent one of the designers there to plan a more mechanical connection. The manager appreciated the ability of the operator and arranged with one of his tool makers to take the young man on as an assistant, and teach him to be a skilled mechanic. The young man became one of the most effective men in that plant for maintaining and improving their special automatic equipment.

Foremen Training Plans

Some plants have established definite training courses for foremen, with classrooms and a definite schedule of classes. Here the attempt is made to educate the foremen so that they can become more effective leaders, and also to train their understudies and other selected men so that they will be better equipped to take over more responsible positions as chances occur. Generally training courses of this sort are a part of the work of the personnel division. They may be given by a

special teaching staff, or by different executives of the organization, or by both. The personal contact between the teachers and the students is valuable, and can be of great assistance in evaluating the potential capacity of the different men.

In many plants, formal training classes are not held, but periodical joint meetings, often preceded by a dinner, are held for members of various parts of the organization. Generally some one topic of interdepartmental interest is brought up for discussion, usually presented by one individual, who may be either some one in the organization or an outside speaker. These, and all other forms of "get-together" activities have their value and promote better personal relationships, but I believe that definite educational projects are of greater value in every way.

In one plant where gears were an important element of the product, the best results that could be obtained for the unhardened or green gears showed errors in action of the order of one thousandth of an inch. Every practical refinement in accuracy of tools and equipment, measuring and other testing facilities, and in control of the physical condition of the material, was introduced, but no further increase in accuracy of product was obtained. It was finally decided to organize classes for the foremen, machine adjusters, inspectors, and those operators who wished to take the course, so that they could study the fundamentals of gear-tooth action and the influence of various types of errors on their performance. These classes were held during working hours, and consumed about one hour each three days a week. After about four months of classes, the average accuracy of the product had improved so that the errors in action of the soft gears had been reduced to about one-half a thousandth of an inch, with no change in the manufacturing equipment.

As another example we cite a company which furnished some sets of gears for use in tests on the Lewis gear-testing machine. This machine has a charting device which records the amount of error in action in the operation of the gears on a chart. The superintendent of the shop was present when the first pair of his gears were charted. They showed errors of about four thousandths of an inch, much to the chagrin of the superintendent. This led to a discussion of the subject, particularly about the probable causes of the errors. Some months later, the same plant sent additional sets of test gears, cut with the same tools on the same manufacturing equipment. The errors had been reduced to less than one-half of those on the first sets of gears, and the same improvement was noticeable in the quieter performance of their product.

The extent of foreman training and kindred educational policies will depend largely upon the general policy of the company in regard to the selection of men for executive and administrative positions. Shall we try to train our own men for bigger jobs, or shall we go outside and get some one already trained? Here we are faced with another problem, and that is the "human inertia" of many men in subordinate positions. The possibility of a new position of responsibility may depend upon the success of some new development under way. No definite promise of this advancement can be made, but the situation can be explained to some of the potentially eligible men, and the opportunity can be offered them of starting with the project and of growing with it. Such an opportunity may be refused because the full reward is not certain, because it means hard work for some indefinite time, possibly a greater responsibility than a man cares to assume, and no absolutely certain reward other than the experience. In such a case it is absolutely necessary to go outside for a man who is willing to undertake the job. Then, if it does go through, much dissatisfaction is expressed by the very ones who had the first chance at it, because the company went outside to get a new man to fill an important job. The best policy, in my opinion, is to train and promote existing members of the organization as far as they are willing to work voluntarily for such advancement, and no farther. When the supply of candidates in the plant is exhausted, others must be brought in.

The argument is sometimes raised that it is essential to introduce new blood into the organization or the shop practices will become stagnant and not keep abreast of current practice. Such conditions do exist, but there is a simple cure for them. This is the policy of sending men outside, from time to time, to visit other manufacturing plants of all varieties, to get first-hand knowledge of what is going on. The men who bring back the most should be sent visiting most often. Those who bring back little or nothing may well be kept at home.

This, in turn, raises the question of the policy of allowing visitors in the plant. In my experience, an intelligent visitor with an intelligent guide always leaves behind more than he takes away, and, paradoxically, the visitor probably gets more than he gives. The general attitude toward shop visits is more liberal today than it was a few years ago. For example, an employee of one plant received a letter from a stranger, as a result of a short article he had written for a trade paper, asking him if it was possible to get permission to visit one of the departments of the plant. It was a new plant and had been built with several innovations in the polishing and plating departments. The employee took the request to the general manager, who was at first re-

luctant to grant it. The policy at the time was that no visitors were allowed. After some discussion, permission was given the employee to invite the man to come, but the employee was to guide him personally.

The visitor arrived, and visited the polishing and plating rooms, escorted by the employee and the foreman of the department. The visitor and foreman discussed almost every detail of the layout, and finally the visitor noticed an experimental set-up in the corner of the plating room. He asked about it and the foreman told him he was ashamed to show it as he had had no success with it. It was an attempt at black nickel plating. The visitor said that he was doing that as a routine job, but he had had many difficulties at the start. He then gave the foreman a detailed account of the starting troubles of his process, and of his present practice as he had it in his mind. He promised to write out a complete account and instructions as soon as he got home. Within a week, the written account was received, and within another week, black nickel plating had been removed from the experimental category.

Another matter affecting the morale of the plant deserves mention. This is the recommendation of present employees for outside jobs. Every executive receives letters, from time to time, asking for suggestions of names of men to fill specific positions. One plant has adopted the following policy: if the management has a chance to place one of their own men in a better position than any they themselves can offer him, they do so, no matter how valuable he is to them. Any expense resulting from this policy can be legitimately charged to good will. In this particular case, to be honest, the motives are not entirely altruistic. Most of such openings are with their own good customers. The resulting good will embraces that of the company and that of the individual; both are valuable, intrinsically and commercially.

Apprentice Training

Even though most of the tasks of production have been broken down into simple elementary ones, a considerable number of highly trained craftsmen are still required to make, to adjust, and to maintain the productive equipment. In times of national emergency, when many new products must be made, and when other production facilities must be greatly increased, the demand for such skilled men soon exceeds the supply. Here we have an acute example of a problem of seasonal employment. It requires several years of training to develop the requisite skill. Furthermore, the type of individual who can acquire this skill can also become proficient in other lines of work. Thus it is natural that there is some reluctance among such men to select a line

of work with a fluctuating demand for their services. In addition, many of these skilled craftsmen find their way into other lines of work when the demand for their talents falls off, and are permanently lost from this type of work.

For many years, most of the older machinery manufacturers conducted definite apprentice training courses in order to maintain their supply of skilled mechanics. With the continued growth of automobile and other mass-production activities, more and more of these graduate apprentices were absorbed by the new industries to meet their needs for skilled tool makers, gage makers, and supervisors. Hence the old apprentice courses were eventually discontinued.

To meet this situation and to provide some plan for training skilled workmen, many public trade schools have been established. By themselves, however, these are not adequate. Both training and actual experience are needed to develop the necessary skill and technique; one without the other is entirely inadequate. The trade schools can give much of the training, but no practical experience.

Today a cooperative plan of apprentice training is being tried out in many places. How well it will meet the situation is still an open question. In general, this plan requires the cooperation of several manufacturing plants with the trade school. The apprentice receives his initial training in the trade school. After he has acquired some proficiency in some of the fundamental types of machining processes, he is transferred to one of the manufacturing plants for practical experience and further training under actual working conditions. Generally he also continues with further training and classroom work at the trade school.

A supervisor of these apprentices is usually appointed by the manufacturing plant. He keeps in touch with them in the several departments of the plant, and tries to see that they are given opportunities at different types of work and in different departments when they have attained proficiency on a particular job. Usually no definite time period is established for each part of the training. The progress of the individual is the principal factor. This often leads to a relation approaching the strained between the supervisor of apprentices and the department foremen. The men who have become the most valuable to the foreman are always the ones that the supervisor wants to take away from him. The foreman is meeting a production schedule; that is his major concern. "You can take all the others and I won't care, but leave that man here because I need him" is generally the answer the foreman gives to the supervisor when told that the latter plans to move some one of the apprentices to another job.

Apprentice training is a nuisance in any manufacturing plant, but it appears to be one of several necessary evils. "By its nature it is a part of our public educational system." Perhaps if it were treated directly as such, and if all additional expenses entailed by the manufacturing plant which operates such training courses in cooperation with the public trade schools were put in the same category as taxes, contributions to educational and scientific organizations, etc., a greater degree of cooperation between these trade schools and manufacturing plants could be reached. At all events, the refusal of any industrial plant to cooperate in such work, unless it operates a complete apprentice training course of its own, is a definite evasion of one of its responsibilities.

CHAPTER VIII

QUALITY CONTROL

Quality control includes all activities devoted to the purpose of insuring a definite quality of product. It starts with the inspection of the raw materials and continues through to the testing of the performance of the finished product, and may even extend to a study of the performance of the product in the hands of the customers to check its performance there. As defined before: "Quality is that which fits a product for a given use, and the word quality is meaningless apart from the use in view."

As an introduction to this discussion, I quote my own paper entitled, "Quality Control and Inspection Gages," presented at the annual meeting of the American Society of Mechanical Engineers in 1929.

Inspection methods and the production gages used have been developed generally around particular commodities. Many measuring instruments and gages have reached a considerable degree of standardization. In general, however, the common practice is to provide limit gages for all specified limiting dimensions, and these gages are made as simple as possible without much consideration to either the relative importance of the dimension measured, its interrelation with other dimensions, or the cost of using the inspection tools. The fact that a dimension on a drawing is given with tolerances is generally assumed as sufficient reason for providing gages for it without further consideration. If drawings were always complete and precise this assumption would be correct, but the technique of dimensioning drawings with tolerances has not yet been fully developed. Considerable progress along these lines, however, has been made by several of the larger manufacturing organizations, particularly those which have extremely large rates of production to maintain.

To obtain data on normal costs of inspection, percentage of spoiled parts, etc., the author addressed letters to a wide variety of industries asking for information. All replies did not give definite figures, but some responded with comments of value. Some of these comments are as follows:

(*a*) "We are unable to state the proportionate cost of our product in terms of gages or inspection as we do not segregate these costs on each individual article, due to the large number of articles manufactured and the extreme variation in design.

"We look upon gages and inspection in the same manner as we look upon machine tools, etc., namely, they are essential to the production of the article,

and the degree of accuracy depends, of course, upon the specific article under consideration.

"Each workman, as well as each tool-setter, tester, and inspector, contributes more or less in normal production to the cost of inspection. Consequently the writer is unable to give any information of value relating to gaging or inspection as proportioned against other costs, such as material, overhead, etc.

"As regards percentage of scrap tolerated, our ambition is to reduce this scrap to zero, which is an ideal hardly attained in practice. We treat each article manufactured as an individual problem, and do not set any limit that might be termed allowable scrap."

(*b*) "Initially, with a new line of apparatus, the first consideration is not what inspection may cost, but rather that the specified performance, interchangeability, and uniformity must be met. It is the responsibility of the inspection department that these requirements shall be met with certainty. The use of gages is a great advantage, but obviously these can only be used for certain classes of work. In most cases the inspector uses the same gages that are used for manufacturing, and therefore no additional expense is incurred for the same except that of checking their accuracy. They are therewith able to inspect more quickly and accurately. This is illustrated by the actual data. The lowest figures in the values given apply to the case of a product consisting entirely of machined parts using jigs, gages, etc., to the fullest extent." [Note: inspection costs without gages are about seven times as great as these costs with full equipment of gages.]

(*c*) "The problem of the inspection department is to perform its functions at the minimum cost. When this cost seems or is high, either due to an excessive amount of defective work or parts, or facilities for inspection, or excessive variation from standard, it becomes a problem for the tool and production departments.

"Whether it is cost of inspection or scrap expense, past experience in the same or a similar product, or the better performance of others, is the only dependable guide. The usual set-up is that whenever any one can show where there is an opportunity for the reduction of cost, or for a saving, their suggestions will receive consideration, and if deemed worthy will lead to a study or investigation."

(*d*) "The direct labor element of inspection may, of course, be a minor part of the cost of quality control. In some industries it would be small in comparison with the laboratory tests performed on raw materials; in some it would be small in comparison to the amount of product consumed in tests. Quality control, or 'what price quality' is so much a part of the duty of the whole manufacturing organization, that it is impossible to estimate what proportionate share of the total cost may be attributed to it."

(*e*) "The amount of gaging on machine work depends on many factors. Its need decreases as the strength of the producing organization increases. It decreases with the fluency of the part in question because of the continued familiarity of the whole organization with the task. It is necessarily large

where a high degree of interchangeability is necessary, or where great hazard may exist in the escape of a product not up to standard."

(*f*) "The percentage of scrap which one is forced to tolerate depends on what the product is, how stable the demand and therefore the organization, and many times on such elements as the weather itself."

(*g*) "There is some fluctuation in the figures submitted when manufacturing is continually increasing its production, necessitating the training of new men. When a factory has had production running normally for over a year, then the figures given would, in our estimation, be fair for our type of work."

(*h*) "The figures given do not represent the total amount of inspection work done by employees, however, nor do they cover the cost of the variety of gages used through the factory, which is considerable. The greater part of our gaging is done by the operators at the points where the different steps of manufacture occur. A large number of our employees have been a long time with the company, and many of them are specialists in the particular operations they perform. Often 50 per cent of an operator's time is spent in gaging the work he produces."

The following statistics on cost of inspection represent the per cent of payroll for inspection as compared with the total payroll factory cost of the product. The per cent of scrapped parts represents the per cent of spoiled parts because of faulty workmanship or material, as compared with the total production. I have tried to separate them into groups which have similar manufacturing problems.

Class A. Household and office appliances such as washing machines, calculating machines, typewriters, telephone equipment, etc.

Cost of inspection	from 2 per cent to 7 per cent
Scrapped parts	from ½ per cent to 5 per cent

These percentages vary in the different departments, the differences depending upon the nature of the production methods and the design and requirements of the components involved.

Class B. Machine tools, electric motors, turbines, etc.

Cost of inspection	from 5 per cent to 7 per cent
Scrapped parts	from 1 per cent to 7 per cent

Class C. Automobiles, agricultural machinery, gasoline engines, etc.

Cost of inspection	from 4 per cent to 10 per cent
Scrapped parts	from 2 per cent to 7 per cent

Class D. Standard small tools, gages, etc.

Cost of inspection	from 10 per cent to 20 per cent
Scrapped parts	from 5 per cent to 25 per cent

Class E. Special tools, gages, fixtures, etc.

Cost of inspection	from 25 per cent to 50 per cent

The cost of inspection on different types of productive equipment, even in the same plant, or on different parts of the product, some simple and others more intricate, varies considerably in these figures. Thus in one plant with an

average inspection cost of about 7 per cent, the inspection costs in different departments vary from 2 per cent to 29 per cent. In another plant whose average inspection cost is about the same, these inspection costs vary from 1 per cent to 67 per cent in different departments.

Even on the same type of manufacturing equipment, these inspection costs vary, depending upon the requirements of the product. For example, in automatic screw machine departments, the cost of inspection on the average product may be as low as 1 per cent or 2 per cent, while on parts with very close tolerances where the product must be watched continually, this cost may increase to over 10 per cent.

One interesting example comes from a large plant manufacturing a wide variety of products. On two similar products, the first having been in production for some time, and being completely tooled up and provided with gages for rapid inspection, while the second had just started in production, was incompletely tooled, and was being inspected mostly with standard measuring instruments, there are the following percentages:

	First Example	*Second Example*
Cost of inspection	1 per cent	7 per cent
Scrapped parts	½ per cent	7 per cent

The initial gage equipment in one plant which is completely tooled up to manufacture a specialized product represents about $10 per employee, and the cost of maintenance of these gages is about one-tenth of one per cent of the factory cost of production.

In "Modern Developments in Inspection Methods," published in the December, 1926, issue of *Mechanical Engineering*, E. D. Hall makes the following comments:

"Inspection in general does not create but rather controls quality. Quality is conceived in the design and given substance in the materials chosen, and form in the manufacturing operations. Given good designs and materials, the manufacturing organization must be held responsible for the construction of a satisfactory commodity.

"However, the executives of this branch have many opposing forces bringing pressure upon them, such as demands for quick delivery, low costs, high earnings for the operators, and quality. Since the first three are immediate and ever present, while the consequences of variations in quality are usually more remote, it follows that the first three will receive the most attention by the branch engaged in producing, and that the supervision and control of quality because of its importance can best be cared for in a separate organization.

"For the same reasons, the head of the inspection work should report directly to an executive who is far enough up the line to give due weight to quality as well as to costs and production."

It should be apparent from this summary of inspection that this function of manufacturing is very closely interwoven with both the design and the methods of production employed.

Divisions of Quality Control

The problem of quality control may be divided into six general divisions, as follows:

(*a*) Preventive measures. This includes all preliminary tests, inspections, and other measures which help to prevent mistakes.

(*b*) Process inspection. This includes all shop inspection made on the parts as they are being machined. Its purpose is to check the performance of the operators and the equipment, and to sort out faulty parts as soon as errors are detected, in order to save the expenditure of additional effort on worthless parts. This process inspection can be organized and operated as a part of the preventive measures.

(*c*) Salvage. This includes the consideration of rejected material to determine whether or not it can be corrected or used, and any other disposition of this material.

(*d*) Finished parts inspection. This is the inspection of the completed component parts to insure that they are adequate for their purposes.

(*e*) Testing of assembled products. This includes all tests of the completed product which are made to insure that it will render its specified service.

(*f*) Checking of actual service performance. This includes all investigations of complaints, studies of actual performance in the hands of customers, and long-time tests or breakdown tests made at the plant to determine the stamina or probable length of useful life of the product.

Preventive Measures

Every precaution should be exercised to prevent the existence of faults in the product. Such measures should be applied to (*a*) raw materials, (*b*) condition of manufacturing equipment, (*c*) accuracy of original set-up, and (*d*) corrections of drawings and specifications when necessary.

Raw Materials

The intensity of the inspection needed for the raw materials depends upon their importance to the quality of the product. The greater their importance, the more extensive this inspection must be; the less their importance, the simpler these tests may be. Thus in the manufacture of ball and roller bearings, where the stamina and uniform condition of the materials for balls, rollers, and races is one of the most impor-

tant elements of quality of the product, the inspection of the materials starts in the steel mill at the casting of the ingot. The chemical composition of the metal must be held within definite specifications. The tops of all ingots are cropped off to remove the pipe at the top and all slag which rises to the top of the mold. The material near the bottom of the ingot is always better than that at the top. Hence for these bearing materials, only the bottom part of the ingot is used. Inspectors representing the interests of the bearing manufacturers are stationed at the steel plant to make sure that all specified precautions are taken there. This inspection of material continues through its entire course of manufacture into bars. When the steel bars are received at the bearing plants, further tests are made of their composition, hardness, and structure, and a close control of all forging and heat-treating processes is maintained as the material is shaped to finished form.

Steels used for cutting tools may not have the inspection at the steel mill—small tool plants seldom buy entire heats of steel at one time—but the bars are tested as thoroughly as bearing materials when the bars are received at the manufacturing plant. A rigid control of all heat-treating operations is maintained during the production of the cutting tools.

Sometimes the exact condition of the material may in itself be of secondary importance to the quality of the product, yet a definite condition is required of it so that the manufacturing processes can be adequately applied. For example, for sheet-metal parts which receive severe bending or drawing, the material if too hard may crack or break during the processing. Some of these cracks may not be detected until after the part has been in service for some time. For some sheet metal parts, the structure must be specified and held within close limits. In addition, it may be necessary to test samples from each shipment of material by actually forming some parts in the manufacturing processes, and then cutting sections from these samples for microscopic examination. This is to make sure that the condition of the material is satisfactory. In other words, standard chemical, physical, and microscopic tests of structure are not always sufficient by themselves to insure the proper condition of the materials.

Most of the larger plants have testing laboratories where samples of all purchased materials are checked against the purchase specifications. Many smaller plants make contracts with commercial testing laboratories to check the conditions of their raw materials.

Some plants operate foundries and forging departments where some of their raw materials are conditioned for the manufacturing departments. Most of these plants have testing laboratories to check the con-

ditions of the materials produced and to assist these departments with technical advice and assistance when necessary. In one large plant which operates a brass foundry, the metallurgist and the superintendent of the foundry, both of whom are technically trained men and on good personal terms, had frequent arguments about many items. The metallurgist had to test not only the raw castings but also many partially finished and finished parts made from these castings. Certain troublesome conditions of manufacture, he was certain, could be materially eased by a little more refinement in the foundry practice. The foundry superintendent could not agree fully with these conclusions. The metallurgist, who had worked in a brass foundry and was reasonably well acquainted with brass foundry problems, was certain that worth-while refinements could be made. After several months of getting nowhere, the suggestion was made that the two men should swap jobs for a month. This was done. Each man called on the other for help from time to time to keep the routine going. Each gained a fuller appreciation of the other's point of view and tribulations. The net result was an improvement in foundry practice and product, a greater respect in each for the other's work and opinions, and more effective cooperation between the metallurgist and the foundry superintendent.

In all cases, the character and extent of the inspection of raw materials should be planned to suit the needs and requirements of the product as it is influenced by the characteristics of these materials. All unnecessary restrictions in material specifications should be eliminated; all necessary ones should be included and checked. Some of this inspection will be conducted by the chemical, metallurgical, and materials testing laboratories. Where size or form is important, this inspection may be given by the regular inspection organization. All inspection of purchased materials, including cutting tools, manufacturing equipment, and miscellaneous supplies should be performed as soon as possible after the material is received, and before any of it is stored or issued for use.

Condition of Manufacturing Equipment

An important move towards preventing the production of a poor commodity is the checking of the manufacturing equipment and processes to be sure that the operating conditions are adequate. Some of this, such as the checking of a new or an old machine for accuracy, may be done before a new project is started. Most of it is done when production troubles give rise to the suspicion that the equipment or the operation of some process may not be in proper shape. When conditions appear to be unsatisfactory in any production department, a

thorough investigation by some process engineers familiar with the type of work performed there is advisable. Often the poor conditions found and corrected by such investigations lead to similar investigations of other departments doing similar work, even though there is no direct evidence that conditions need improvement.

In every organization, the amount of immediate or critical work for any group or individual varies from time to time. Each has some periods of actual overload and other periods of underload. One good method of reducing the peaks and of filling the hollows is to have a definite program of "fill-in" work, that is, worth-while tasks to be done as the stress of circumstances permits. If such work is carefully selected and organized, it should, when accomplished, help to reduce the intensity of the peak loads. Thus each process engineer should have the responsibility of checking conditions on the type of process for which he is responsible when he is not engaged on specific projects. In a large plant where several process engineers are engaged on the same type of work, it is a good plan to have one process engineer review the work of some other. This should not be done in a spirit of fault-finding, but rather in a spirit of sportsmanlike competition. Each engineer should be able to learn much from the efforts of the other.

When definite troubles are present, however, immediate steps must be taken to investigate them and to correct them at their sources. For example, considerable trouble was being experienced in the plating department of one plant. A process engineer, a trained chemist and metallurgist, who was familiar with the theory and laboratory technique of plating, but who had only a casual knowledge of commercial plating practice, was assigned the task of investigating the plating and polishing department. He found that the cleaning processes were inadequate, that no particular control was exercised over the electrical current or rate of plating, that only the crudest tests were made to test the condition of the plating solutions, and so on. Simple but closer controls were suggested, both for the rate of plating and the condition of the plating solutions, together with suggestions for more effective cleaning of parts before and during the plating operations. These suggestions were adopted, and this process engineer worked with the foreman of the department until practically all the difficulties had disappeared. Incidentally, the shop cost of plating was materially reduced.

The general manager of the plant was delighted with the outcome of this investigation and assigned the same man, after he had completed his work in the plating department, to an investigation of the department where parts were japanned, enameled, and varnished. The conditions were better here, and no outstanding difficulties were being

experienced, but he thought a critical survey might reduce costs. After a month or six weeks of study, the process engineer was able to make a few minor suggestions which resulted in a slight improvement and reduction of shop cost in that department also.

The general manager was pleased, and again assigned this man to a similar task, that of investigating conditions in the heat-treating department. The foreman of this department was a technically trained man, much interested in the heat treatment of steel, who tried to keep abreast of progress in this field. He tried out each new improvement that came to his attention, and put it into practice as soon as it had proved itself. He knew far more of his specialty than did the process engineer who was investigating the conditions in his department. In fact, it was a valuable educational experience for the process engineer, and he so reported it with no suggestions for improvements. The general manager was disappointed at this result, and felt that he had wasted money on this last investigation. To my mind, the last report should have given him the greatest satisfaction.

Accuracy of Set-Up and Process Inspection

When any change is made in the set-up of the equipment for a specific operation, including the original set-up when the project is started and the resetting of cutting tools after sharpening, or the readjustment of the machine or tool to compensate for wear or loss of adjustment in operation, several pieces of work may need to be machined before the adjustment is completed. Before this operation is started in production again, the first piece produced after the adjustment has been made should be carefully inspected. This practice is known as first-piece inspection.

While any given set-up is operating, the product should be inspected sufficiently to insure that the conditions of the set-up remain correct. This is commonly known as process inspection. The amount required depends upon the nature of the operation and the consistency of the process. Where the conditions are all controlled mechanically, as they are on most automatic machines, a periodical inspection of current production is generally sufficient. If the parts inspected are within the dimensional specifications, all parts machined during the period will also be correct. On the other hand, when the conditions are controlled manually, and the operator must give constant attention to his work in order to maintain uniform sizes, the uniformity of this product will depend upon the fidelity of the operator. With some, it may be necessary to check every piece produced; with others, a periodic inspection may be sufficient. This is a problem for the process inspector to work

out for himself. This can be done as the inspector becomes thoroughly acquainted with the performances of the individual operators. On the other hand, if the process inspection is applied as a routine task on the entire product after certain critical operations have been completed, the work is delivered to an inspection station or bench, and it all receives complete inspection. Much of this work is done by girls, with a supervisor to instruct them and to check their performance by periodic re-inspections.

As an example of periodic inspection of the work produced on automatic machines, the practice in some plants may be cited. Numbered receptacles for automatic screw machines are provided to receive the finished parts as they are completed. These numbered containers are used in sequence. When one is filled, it is removed from the machine and set on a bench, and the next is placed in position in the machine. These are arranged in order and kept there until the process inspector comes on his periodic visit. He inspects a few parts from each container. If they are correct, the complete group is accepted; if not, and the parts at the tops of the first few boxes are correct, and parts in the subsequent ones are at fault, the parts in the first few are accepted and the remaining ones are rejected. The machine should be stopped and readjusted by the operator. This done, the inspector should be called back to approve the new adjustment, then the machine is again started in production.

Many similar methods of periodic process inspection are followed. In one plant making threaded pipe fittings, inspectors were assigned to check the product of specific groups of automatic threading machines. They progressed from machine to machine, checking the last piece produced. If correct, they passed on to the next machine; if not, they stopped the machine and left a tag which indicated the fault. The tool setter of that group of machines then made the necessary corrections and called the inspector back for his approval of the first piece completed after the correction had been made. Then production was resumed.

This practice did not prove entirely satisfactory because a considerable number of incorrect parts were made before the error was detected. After some consideration, the routine was changed so that every inspector checked the product from all machines, one inspector following the other at definite intervals of time. The inspectors were instructed to stop the machines when the sizes of the threads approached closely to the rejection limit, and not wait until these limits were actually exceeded. Then when one inspector stopped a machine which was producing spoiled work, the preceding inspector was asked to explain why

he had permitted the machine to continue after his last round. This practice proved to be more effective than the original one.

All inspection is expensive and adds to the cost of production. Unnecessary inspection is of no value, and the problem is to determine the most effective procedure, that is, the least inspection which will insure the desired quality of product. A little inspection at an effective station will cost less and be more effective than a greater amount at some less effective place. Preventive measures at strategic points give more insurance of good quality at less cost than any other practice. For example, a plant making transmissions for automobiles was having much trouble with noisy gears on one particular model. Transmissions were assembled, tested for noise, and the noisy ones were disassembled and other gears substituted. The conditions were so bad that about five transmissions were assembled, four were torn down again, and one was passed. About a dozen inspectors were employed in testing and matching pairs of gears that would run together with the least noise. This selection was in addition to the casual process inspection given to the product. To improve these conditions a careful examination was made of the condition of the gear-cutting machines and of the cutting tools. Most of the machines needed some corrections, and many of the cutting tools were too inaccurate to be used. After the machines had been reconditioned, and a sufficient supply of accurate cutting tools had been selected from the tools on hand, some of them new and others that had been resharpened, conditions were materially improved. A rigid process inspection was organized to keep these manufacturing conditions in proper shape. Only six process inspectors, alert to the faults to be guarded against, were required, and the twelve inspectors matching the finished gears were no longer needed. With this control, only about one hundred and fifty transmissions were assembled for every one hundred shipped.

As another example: an outside inspection organization was called upon to check the quality of a very large quantity of galvanized-iron sheets which was to be shipped abroad. This inspection was to be performed in the plant of the manufacturer of the galvanized iron. One of the officials of the inspection organization visited the plant of the manufacturer to determine the most effective stations for inspection and to organize this project. For checking the adherence of the galvanized coating, he decided that, if he had the sheets watched as they went into the finishing rolls after the galvanizing, any blisters present could be detected as they reached these rolls and were flattened. He therefore stationed two men there, one to watch the top of the sheet while the other watched the bottom.

When production was started on this order, not a single sheet was accepted. All had blisters which were crushed by the finishing rolls. At the end of the first day the production crew at the plant were frantic. The official of the inspection organization was still there, and they stormed at him and insisted that he must ease up in the severity of his inspection. This he refused to do, but he told them that he thought he knew the cause of the trouble: although this was none of his business, he was willing to help them if they wished it.

After considerable argument, they asked him what he thought the cause of the trouble was. He told them that he had been looking over their processes, and he did not believe that the sheet was thoroughly cleaned before it went into the galvanizing bath. Under protest, they drained the cleaning vats, scrubbed them out, and refilled them with clean water and new cleaning compounds. The next day and for a considerable time afterwards, all the product was accepted. Then blisters began to appear again, and an increasingly larger amount of the product was rejected.

Again under protest the cleaning vats were drained and scrubbed, and a good product was produced. This cycle of events continued over and over again until the order was completed. Although the cost for this cleaning was slight, the galvanizing crew objected to cleaning the vats more frequently than usual.

Correction of Specifications

The need of many corrections in the amount of the tolerances and often in the location of the dimensions, as well as the inclusion of much information which had been omitted, becomes apparent as the product is inspected. Whether or not these corrections are made depends largely upon the inspection policy and on the intimacy of the relations between the inspection group and the design group. In many plants these relations are not close, so that some agreement is reached between the inspection organization and the production group to ignore certain parts of the specifications which are manifestly incorrect. The design group knows nothing of this, and so continues to make the same mistakes over and over again.

This condition is often the result of the attitude of the design group, which feels no responsibility for a production design, and is willing to let the shop worry over details. As an example: an officer had charge of design in one of our arsenals. He refused to permit the addition to a drawing of certain explanatory notes which would make it more specific, commenting that he expected the inspector to have and to use some common sense.

If the inspection department has a fixed policy of accepting all parts that meet the current specifications, and of definitely rejecting all parts that do not, then such mistakes and omissions will soon come to light. If the rejected parts are fully adequate for the service they must render, then the specifications should be revised to cover them. If some requirement other than the one specified is needed to make serviceable parts, then the specifications should be corrected accordingly.

The rejection of any parts of the product does not necessarily mean that they must be thrown away or scrapped. They may sometimes be reworked and made serviceable. At other times the violation of the specifications may be the result of some mistake in manufacturing which does not affect the usefulness of the work produced. No revision of the specifications is then necessary, and some procedure can be adopted to permit them to be passed for assembly. For example, in one plant, the rule is that the inspector must definitely accept or definitely reject all parts submitted to him. If any parts are rejected, the foreman of the department who made them can make out a slip requesting that they be passed for assembly when he believes that they can be used. The inspection supervisor for that department endorses this slip, either favorably or otherwise, according to his opinion. With a favorable endorsement, the chief inspector passes the parts for assembly if he is satisfied that they are adequate. They are still rejected parts, however, as far as the records are concerned. If the endorsement is unfavorable, the matter is referred to a salvage board for disposal. The foremen will argue for hours to have the inspector overlook some discrepancy in their work, because they hate to make out these slips. Their dislike of it is so great that it has proved to be one of the most effective means of keeping them on their toes to avoid having such mistakes made in their departments.

An example of an error on a drawing that went uncorrected, and may even yet be uncorrected, is the following. A company that had manufactured certain equipment for several years was very busy, and so sent out some of the units for this product to be made by outside contractors. One of these was a clutch which contained several springs. After the contractor had made and delivered these clutches, they were tested and found to be too weak for the job. The contractor was notified and sent one of his men to investigate. A comparison of the clutches with one of the company's own manufacture soon disclosed that the springs in the contractor's clutches were much weaker than the ones actually used by the manufacturer. One of the men then remembered that they themselves had found, when the first experimental model was made, that the springs specified on the drawings were too weak. They

had had to substitute stronger ones. These stronger springs had been used ever since. The springs were made by an outside spring manufacturer, and new lots were ordered from the specifications of the last order, and not from those on the drawings. This had been going on for several years, but the drawing room knew nothing about it so that the drawings had not been changed. Conditions such as these are very common, and continue to exist because of the absence of any direct channel for the continuous flow of information from the shop back to the drawing room. All traffic is one way, from the drawing room to the shop.

Salvage

As noted before, the rejection of work does not necessarily mean that it must be scrapped. When the rejections are few, it may not be worth while to give them further consideration. It might be best to scrap them at once, but if the number of rejections is appreciable, some consideration must be given to their disposition. In some plants there is a definite salvage committee which meets periodically, or at special sessions when conditions require, to consider the disposal of rejected material. Committees like this are generally composed of representatives from the inspection, production design, and production groups. Other individuals may be called in at times when their interests are involved. This salvage is exclusive of the disposal of chips and other waste materials that collect in every plant.

When an appreciable number of parts must be reworked before they can be restored to the regular production line, it is well to have this work done in a special department, if possible. In any event, it should be done on equipment which is not in use on routine production.

The disposal of chips and other waste material should be assigned to the plant engineering department, as this is a general plant service. Some of this waste may be used as fuel, as in a lumber mill where most of the waste is fed to the boilers. If some of the waste is reclaimed and made into by-products, such work belongs to the regular production group.

Finished-Parts Inspection

After the component parts of the product have been completed, and before they are sent to the finished-parts storeroom or assembling department, they should be inspected to insure that only serviceable parts are accepted. This is a check on the effectiveness of the process inspection as well as a sorting operation when needed because of incomplete process inspection. In some places, however, if this inspection reveals

the need of sorting, the parts are sent back to the production department for this purpose. Many functional gages can be used effectively at this finished-parts inspection, in place of a complete set of limit gages for every machined surface. With an effective process inspection, the finished-parts inspection can be reduced to the testing of a predetermined percentage of parts chosen at random, mostly with functional gages.

The practice of a percentage inspection is often followed for the checking of finished parts made by an outside contractor. One problem is to establish suitable percentages for such control. This subject is discussed in detail by Dr. W. A. Shewhart in his book, *Economic Control of Quality of Manufactured Product.*

When the process inspection is under the jurisdiction of the production department, the finished-parts inspection must be much more complete than when all the inspection is supervised by an inspection group which is independent of the production department. On some government contracts, this finished-parts inspection is a complete re-inspection of every element of every part, as well as functional-gage inspection of every part.

As noted before, inspection in itself adds nothing to the quality of the product. With careful planning, cooperation, and organization, much duplication of inspection operations can be eliminated. For example, at one time the writer had charge of the inspection of parts for fuses which were being made in several plants under sub-contracts. All these plants made watches or parts for watches. One had the contract to make the arming unit. On my first visit to this plant, I found that one wing of the factory had been set aside for this work and that an independent staff of operators and supervisors had been organized. They were just about ready to start production, and my visit was made to check the manufacturing conditions and the first samples of the product and to organize my inspection. I had a high opinion of the plant and carried a watch of their make. The conditions which I found in this special department, and the general quality of the sample parts they submitted to me were disappointing. At a conference with the officials of the company, I expressed my disappointment. In addition, I stated that if I were in charge of the plant and expected to make good watches after this work was finished, I would be afraid of having such work done in my plant. I had hoped that the work would be considered as part of the regular production, and be checked by their regular inspection force. In that case, I would not need any inspection force of my own, and one representative could work with their chief inspector and take care of all other routine duties. The superintendent of the special

department asked for specific details of conditions of the product which I could not accept. I started to give them, but was interrupted by the president of the company. He said: "I see your point and think you are right. Please forget this visit and come again when we send for you."

Some weeks later I was at this plant again. The job had been reorganized as an integral part of their watch production, and the quality of the work was that of watch work. I expressed my gratification and suggested that perhaps they had gone too far. They re-assured me and said that they had found it to be actually cheaper to use the methods and practices with which they were familiar, than to try short cuts and new methods. The whole contract was completed with but a single representative working with their own chief inspector, and no fault was found with their product at the loading and assembling plant where it was tested functionally before assembly.

Testing the Assembled Product

The assembled product is tested by checking its performance in the type of service it is designed to render. Where adjustments are needed to perfect its performance, they are generally made as a part of the testing procedure. A typewriter, for example, is tested by its performance in typing letters. Some of this may be done manually and some of it performed mechanically. Similarly, a sewing machine is tested by actual sewing, etc. These tests give a measure of the performance of the product when it is new.

To check the performance after considerable use, or to determine the probable length of useful life of a product, a small percentage of it may be selected for continued service, or for overload tests, or for tests to destruction. For example, a limited amount of steel pipe will be taken for bursting tests under hydraulic pressure to insure that it is strong enough for a specified use. Again, the manufacturers of ball bearings take samples from each lot of manufacture and test them at a given speed and load until they fail or have run under these conditions a specified number of revolutions, sometimes over one hundred million cycles. Load-speed ratings are established from such tests, and samples from current production must meet these ratings.

Many other kinds of endurance tests are constantly being run, sometimes by the manufacturing organization and sometimes by an outside testing laboratory. Many such tests are made to prove the stamina of a new design or of a proposed change in design. Several testing laboratories are operated by trade groups to obtain information about the service performance of their product, and to prove that it will meet definite specifications of performance.

Inspection Equipment

The inspection equipment includes many types of standard and special measuring instruments, as well as testing machines of many kinds. Most of the inspection equipment used on the component parts consists of measuring instruments. Standard measuring instruments are used when the amount of measuring of specific or similar sizes is not extensive. For routine inspection of large quantities of parts, gages of many sorts are used. For checking sizes between fixed limits, comparators, dial indicators, and limit gages are used extensively.

The limit gages may be of fixed size or they may be adjustable. In either case, they themselves must be checked frequently because of wear in use. The adjustable gages can be reset when worn and returned to service. Limit gages of fixed size must be repaired or discarded when they have worn beyond their rejection limit.

Minute differences in the sizes of duplicate limit gages are the source of many arguments in the shop. If the gage used at the machine by the tool setter differs from the one used at the bench by the process inspector, parts near in size to the rejection limit may be accepted by one gage at the machine and rejected by the one at the inspection bench. If similar limit gages are used for finished-parts inspection, differences between them and those used for the process inspection will stir up further dissension.

There are some advocates of a policy which provides two classes of gages, as regards their size: working gages and inspection gages. The working gages are made inside the limits of the inspection gages whereas the inspection gages are held as closely as possible to the extreme limits of the product. As long as the gages maintain this small relative difference in size, any part which passes the working gages will unquestionably pass the inspection gages, but both sets of gages will wear in use, and the amount of wear may be more on one set than on the other. With such changes in size, the original conditions may soon be reversed. There is another argument against this practice, unless the tolerances on the product are very liberal. The actual tolerances and wear allowances on two such sets of gages must be held very small, if the product tolerance is small, or a large part of the product tolerance will be consumed by the gage tolerances. Hence the initial cost of these gages is high and their useful life is limited.

Where continuous production is involved, it is a better plan to have only one specification for all new gages for a specific component part. Then, when they are in service, all gages for a given part can be periodically collected and rechecked. From the very start, and throughout the useful life of the gages, all gages in use at the same time can be

sorted according to their size. Those closest in size to the extreme limits of the product should be used on the last inspection, whereas those which are the greatest amount inside of the product limits should be used at the machines. Those intermediate in size should be used for the process inspection, when a separate set of gages is used for this purpose. Thus a given gage may shift from one inspection to another, according to its size in relation to the sizes of the other gages in service at the same time.

Sometimes it seems as though the more trivial a matter is, the more heat it can generate. This is true in regard to these minute but inevitable differences in the sizes of limit gages. When acting as an inspector for the purchaser in the plant of the manufacturer, my own practice has been, whenever parts were rejected which had been accepted by the gages used by the manufacturer, to ask the manufacturer to let me have the gage he used. If, when the gage was measured, it was not outside of the product limits, and it passed the work, those parts were accepted without further question. On the other hand, if this gage had worn beyond the limits specified for the product, or if the work would not pass the gage submitted, there was seldom any further argument.

When the amount of inspection is large, frequently a special automatic gaging machine is designed and built, so that all inspection which requires a sorting of the parts is done mechanically or electrically. Some of these special gaging machines sort out the oversized and undersized parts from the rest of the product. Others sort them according to size for selective assembly. Still others not only measure the physical sizes but also test some of the physical or operating characteristics of the product.

For example, special automatic-gaging machines are used in several plants to check the critical dimensions of military cartridges for rifles and machine guns. These machines reject and eliminate from the ones tested all cartridges which are outside of the specified limits.

A simple but effective automatic-sorting machine is used to select balls of almost identical size for use in ball bearings. The balls are sorted into different compartments according to their diameters, so that all the balls in any one compartment are alike within a very small variation in size.

An automatic machine is used for testing fuses used in telephone circuits. This machine not only checks the diameters and lengths of these units, but also rejects any "dead" ones by passing an electrical current through them at one of the inspection stations. If the fuse is "dead," and no current passes through it, it is ejected automatically. If the current does pass through, that fuse remains in the lot.

Another automatic-inspection machine is used to check the capacity of small condensers used in telephone circuits, and to sort them according to their measured capacity. This permits their selective assembly into pairs which have almost identical capacities.

Quality Control Practice

The actual practices followed in industry to control the quality of the product are many and varied. These range from that of the small shop, which expects every workman to do his own inspection, to that of a very large organization where high quality is of paramount importance, and where an extensive plan for checking and rechecking the work through all stages of production has been carefully worked out. These conditions can be presented best by definite examples.

The first is that of a large producer of electrical equipment. Here we have three groups or departments each of which has a definite interest in the quality of the product: first, the research laboratory which is the authority for the functional design and the characteristics of the performance in service; second, the manufacturing engineering department which controls the production design, operation lists, tool design, and all other duties of preparation, and which is responsible for the performance of the equipment until after the first production is actually under way; third, the operating department which makes the component parts and assembles them. The process inspection is a part of the work of the operating department. The finished-parts inspection is conducted by the manufacturing engineering department by specified percentage inspections of each different component part. If these tests are not satisfactory, and some sorting is necessary, the parts are returned to the operating department for this sorting. The testing of the assembled product is conducted by the manufacturing engineering department, coupled with a percentage retest by the research laboratory. Here we have a check and recheck at every successive step in the production.

In another large plant manufacturing a single specialty, the inspection department is an independent organization responsible to the general manager. The manufacturing is done in specialized departments, so that any one component part may travel through several different departments before it is completed. The parts are relatively small and are transferred in standard tote boxes on trucks. The inspection department is located near the center of the plant. The process inspection is conducted by the department foremen and machine adjusters. When any parts are transferred from one department to another, they must pass through the inspection department. If the foreman of any department has doubts about the condition or accuracy of

partly finished components delivered to him, he must take the matter up with the inspection department before he does his work on them. After the parts are finished, they are delivered to the inspection department for the finished-parts inspection. All parts accepted are sent to the finished-parts storeroom for issue to the assembling department or to the service men as they call for replacement parts. All parts rejected, whether partly or completely finished, are sent back to the manufacturing department from which they were received. This department must rework them if they can be salvaged, or be charged with their cost if they must be scrapped. The testing of the assembled product is done by a separate group in the assembling department. This work includes both the adjustment and the functional tests.

In another plant manufacturing several sizes and models of a specialized product, the chief engineer has two staff assistants: one, the chief designer, and the other, the chief inspector. Here inspection and quality control are an integral part of the engineering department. In addition to the force of regular inspectors stationed permanently on the production floor, all designers must spend definite periods of time with the inspection group in the shop, acting as supervisors or performing some of the actual inspection operations as conditions require. For example, when the design of a new product has been approved for production, and the new tools have been designed, most of the engineering group which has carried this work through the drafting room is transferred to the inspection group in the shop, while a similar number of designers who have been working there are transferred back to the drafting room. As difficulties may arise, the shop superintendent and department foreman deal directly with the men who have planned the work. If a change in design is desired to facilitate manufacture, and this change will not affect the functional operation of the product, the change is approved directly and the necessary information is sent to the drafting room so that the drawings and other records may be changed and kept up to date. If the change requested affects the functioning of the product unfavorably, the designer is there to explain why that change cannot be made. Such service in the shop helps to develop some very effective designers. In addition, copies of all complaints from customers are sent to the engineering department, and this department investigates all complaints that touch on the performance of the product in service.

It is my firm belief that quality control is an integral part of product engineering. The practice just described is a logical and effective method, not only of controlling the quality of the product but also of giving the product engineers the kind of information they need to make their new designs more effective and of higher quality.

CHAPTER IX

COST REDUCTION

In all production there is a constant search for ways and means of reducing the factory cost of the product. This is in addition to the efforts which are made to choose the most economical methods for the production of a new commodity. At the start of production, elapsed time is usually an important factor. At this stage, we must choose tried processes and methods rather than experiment too widely with schemes that may be cheaper if they work but may require additional time to perfect. After production is started, however, we should review critically all our operations, make minor experiments on the side if necessary, so as to reduce the cost of production as much as possible. In many respects the distinction between the selection and planning of methods of manufacture in the preparation stages, and their reconsideration and improvement after production is under way is much the same as the distinction between the functional design of the product and its production design. In both cases, the second stages are never finished.

There is a constant and growing demand for the seemingly opposed factors of higher wages and lower costs of products. These demands can be met by a more effective use of materials and productive facilities and by more efficient methods of distribution of manufactured products. Thus far, most of the burden has been placed upon the shoulders of factory management and production engineering. The cost of distribution alone is often equal to, or even more than double the entire factory cost of production.

When searching for ways of reducing the cost of manufacture, reduction of cost should never be the only objective. With sufficient study and persistence, when the amount of production is large enough to warrant a thorough investigation, it is always possible to find or to develop methods that will both reduce the cost and improve the quality of the product. Where reduction of cost is the only objective, a deterioration of quality is all too probable.

A large textile plant had developed over a long period of years a special finishing process that produced a very fine quality of product which was unique in its field. With a re-organization and a search for lower costs of production, new people were brought into the organ-

ization who lacked the traditional training, and some of the older members of the original group were released. Each new group that was brought in made minor changes in the processes that reduced the cost and did not make any apparent difference in the quality of the product. After about two years of changes that constantly reduced the factory cost of production, the market for this specialty was suddenly reduced in size. An investigation then showed that, although no single change had resulted in any apparent loss of quality, the cumulative effect of all the changes had resulted in a very definite loss.

All cost reduction efforts should be definitely coupled with an attempt to improve the quality. A policy of "good enough" is a definite step downwards. We also have the problem of improving quality without incurring additional costs. Some of these improvements may be necessary to meet the complaints of customers; others may come as suggestions from different members of the organization. In general, suggestions of this sort are received with little enthusiasm. One process engineer had made several suggestions of this sort, only to have them turned down because the existing product was felt to be as good as any made by competitors. Finally he protested with the statement that if the company was satisfied with the goal of "as good as our competitors," its product would never be quite as good as the others.

It is easy to understand why a production organization with an established market does not want to make major changes in an established product. All major changes are forced upon it, directly or indirectly, by its customers. The automobile industry, for example, is experimenting with and testing many new devices and improvements in their mechanisms. Some few new ones are introduced every year. Many others are held back because the cost of the change-over will be too great to be absorbed in a single year's production. If, however, the sales of new cars begin to decline, a larger number of these new features or improvements will be included in the next model.

Some years ago several small plants started to produce ground tools of a specialized type, largely for local customers who needed something better than the commercial unground tool. None of the larger manufacturers of the commercial tools were interested enough to equip their plants with the necessary special grinding equipment. The market was small, and such tools were classified as special ones. In a few years, users of these tools discovered that although the first cost of these ground tools was higher than that of the commercial unground tools, they lasted longer and produced a better product so that the actual cost of production was no greater. They then began to use them on all jobs, whether the increased accuracy was needed or

not. It was not until the manufacturers of the commercial tools suddenly discovered that they were losing a considerable part of their market that they provided themselves with the equipment to grind these tools.

Another example is that of the oil-well operators who for several years had tried to persuade the manufacturers of one important part of their equipment to produce it in larger and different sizes and of materials with higher physical properties than their standard product. They had little success. Eventually, after continued and combined efforts, these manufacturers met them part way. Then the oil-well operators imported from abroad a shipload of this material that met their needs. It was not long after this that some of the American manufacturers equipped themselves to furnish the improved product which had been demanded.

Many progressive plants make a definite and consistent attempt to study all possibilities of reducing the factory cost of production and of improving the quality of their product. Effective cost reduction measures require the cooperative efforts of all parts of the factory organization. In particular, the process engineers should be constantly trying to achieve these results. This might well be a definitely assigned task for any slack periods in their work. In one plant, each tool designer is given a list of component parts with instructions to survey the methods of production in use as he finds time. To study one of these component parts, he takes the operation list as it appears in the records, and goes out through the shop to check the actual procedure against this record. Changes in sequence or methods are noted and he must bring these records up to date. If he can suggest any change which will either improve the product or reduce its cost, this suggestion is submitted with his report on the operation list. These suggestions are considered, adopted if thought to be of immediate value, and filed for future reference when not adopted immediately. Each component part is surveyed in this manner every year. In addition, a record is kept of the name of the one who surveyed it, and the next year the task is assigned to a different person. This plan has the advantage of sending the tool designer to the production floor with a definite task, and gives him the opportunity of seeing the actual performance of the different types of equipment which he is called upon to design.

There are so many possible ways to reduce costs and to improve the product that any attempt to list them all is incomplete. Among them are the following:

Re-arrangement of Manufacturing Facilities

Detailed motion study of a specific manufacturing operation often shows that some change in the arrangement of the set-up, or in positions of containers for parts on assembling operations, will shorten the motion or reduce the number and variety of motions required of the operator, and will thus reduce the amount of time and effort which must otherwise be consumed.

A survey of the sequence of production operations on a component part may show that a change in the order of operations will make some other operation easier, or may possibly eliminate the need of some succeeding operation. For example, a difficult filing or burring operation may be made simpler by a change in the sequence of the operations which will leave the burr in a more accessible place.

A study of the traffic conditions in the plant may make apparent some possible savings which would result from a re-arrangement of some of the productive equipment by reducing the amount of trucking required.

It is true that all these factors are, or should be considered in the original planning. Yet our imagination or foresight is limited, and the actual observation of existing conditions often shows apparent oversights or conditions which can be improved.

Improvements in Tools and Methods

When planning for the production of a new commodity, if a definite time schedule must be met, we must select methods which have already been proved in practice. Even though experimental work on some new or modified process is well along, and final success seems near, it is a bad mistake to plan to use it on a new manufacturing project. Too often, the last refinements which are needed to perfect an experimental process take much more time to discover than is anticipated. To use the process in its incomplete state is to transfer experimental work to the production floor. In almost every case, the last few degrees of refinement are the hardest to obtain.

Even when we try to duplicate existing methods on new work, there are always some factors which are different, or new, as compared with our existing practices. After the operations are actually under way, we can always find some details which can be improved. Some of these improvements are obtained by surprisingly small changes; others require entirely new tools for the operation.

As an example of the great influence of small changes, there is the classic story of the operator of some mechanical spinning frames in the early days, shortly after power equipment was first introduced in

the textile industry. The story goes that one operator had very little trouble with the breaking of thread on his spinning frames while all the other operators were continually in difficulties. His actions were carefully watched in the attempt to discover how he was able to prevent this breakage of threads, but without success. As far as could be seen, his actions and methods were the same as those of the other operators. Finally he was asked how much payment he wanted to disclose his secret. At first he denied that he had any. After much persuasion, he named his price, the guarantee that he should have a pint of beer every day as long as he lived. The bargain was struck, then he said: "Chalk your bobbins."

This operator carried a piece of chalk in his pocket. Whenever he had to change a bobbin, which was made of wood, he rubbed his hand on the chalk in his pocket and then rubbed the bobbin. The chalk dust was sufficient to prevent the fibers of the thread from catching on the fine splinters on the surface of the wooden bobbins.

Another example is that of minor improvements in small bench machines which wind silk insulation on fine copper wire. When the spindles of the original machines ran faster than about four thousand revolutions a minute, the insulation threads broke too frequently. The spools of insulating threads were carried on the end of the revolving spindle in an open frame, consisting of four pins with a restraining ring at the front. The multiple threads were led over one of the pins, then through an eye in the ring at the front, and then down to the end of the spindle where they were wrapped around the wire. The wire did not revolve, but was fed through the hollow spindle of the machine. The breakage at higher speeds was caused by the windage in the open frame acting against the threads as they went out over the pin and back to the spindle again. There was also some unbalance that affected the evenness of the winding when the speeds were increased.

The shafts were balanced, and a thin-walled tube or pipe was substituted for the open frame. A slot was cut in this tube for the multiple threads and an eye was made near its outer end. This closed construction eliminated the windage against the strands of thread as they were fed out and in again. The windage against the threads as they passed over a part of the outside of the tube from the slot to the eye flattened them into a ribbon, a condition which persisted from the eye to the spindle nose. This improved the smoothness of the winding. These changes permitted the machines to be run at double the original speed. In addition, the improved operation of the machines made it possible for one operator to tend twice as many machines as before, and with even less effort for the operator. New machines were made and in-

stalled, and about four times the former amount of production was obtained with the same number of operators.

There is no general rule or technique for cost reduction activities. Each problem is an individual one. The only definite statement that can be made is that unless we have reached the point where we cannot learn from experience, there is always a good chance for improvement on any of our manufacturing operations.

Substitution of Methods

New and improved methods are constantly developed, not only in our own plant but also by others. A new process may be introduced into the plant for a particular project. After we have mastered its operation, an investigation generally shows many places where it might to advantage be substituted for existing processes. It may be that this investigation is started because the particular project does not use the new equipment to its full capacity. Then we look for other work which can be handled more expeditiously by the new method and so keep the new equipment busy. Or it may be that the new process has proved so effective that we look for more work for it to justify the purchase of additional equipment of the same type. Take for example the process of surface broaching. This is a process which has been developed as a substitute for milling. We may obtain a surface-broaching machine to produce parts for a new product. As we become better acquainted with its advantages and limitations, we are convinced that we could use this process to advantage in many other places. After a survey, we find that we can use more of this type of equipment on several operations, so we obtain the additional equipment and use it accordingly. Sometimes this change of process involves minor changes of design of the product itself. These should be made whenever they do not affect the good quality of the product.

Sometimes a new process is suggested which will do the work more effectively than the one in use. This suggestion may need to be worked out experimentally before the actual production tools are made and installed. For example, several keys were required on some small cold-rolled shafts to drive gears or levers mounted on the shafts. The loads were very light, and the existing practice was to drill a hole through the shaft and press in a small pin. The projecting end of this pin served as a key to fit the keyway in the mating member. The suggestion was made that the metal of the shaft be pinched so that it would be forced up by plastic flow to form the key integral with the shaft. An experimental die was made which was operated by hand in a bench vise. The die consisted of two blocks of steel, doweled together, with

a hole the size of the shaft drilled with its center line at the junction of the two parts of the die. A second hole was drilled through both blocks at right angles to the hole for the shaft, and with its center line above the center of the shaft hole. Two punches were made to fit the cross hole, their lengths shorter than the thickness of the blocks by one-half the thickness of the key required. The shaft was inserted between the two halves of the die and the two blocks were clamped together. The two punches were then inserted and their projecting ends were pushed home until their ends were flush with the edges of the die blocks by the pressure of the vise jaws as they were screwed together. This pinched the metal of the shaft into a very satisfactory key. Some experimental work was needed to determine the most effective size for the punches, and their positions in relation to the shaft. When this work was completed, production tools for use on a punch press were designed, built, and put into operation. This change materially reduced the cost of production. This is another case where a cold working process was developed to take the place of metal cutting processes.

As other examples, many different types of welding processes have been developed and are being improved constantly. Welded frames are now being substituted in many places for castings and forgings. This includes machine frames, electric motor frames, large gear blanks, and many other machine parts. Such processes are frequently used in place of riveting. The design of some of the component parts of the product must often be changed considerably if the full advantage of these welding processes is to be had. These changes include both differences in forms and changes in the materials employed.

Substitution of Standard Tools for Special Ones

Whenever any tool or other element is used which is special, and standard tools or elements are available which nominally cover the particular field, that special element should always be kept on the defensive. In other words, the need or advantage of departing from standard should be questioned, not once, but over and over again. It may be that a change or an improvement in the standard has eliminated the need for, or canceled the value of the special construction. These standards for tools may be those of some standardization committee or of some engineering organization, or trade association, or equipment or tool manufacturer, or of the plant itself.

Before tools can be adequately standardized, the design of the product itself must conform to definitely established sizes and forms. A new product may be designed which uses some mechanical element not present on any of the other existing products. There may not be

any general standard available for this element. Here a special design and special tools must be used. As time goes on, other new products are designed which use the same type of element, but of different size than the original one. It has already been classified as a special or non-standard element, hence it is designed to suit its purpose without reference to any previous one of the same general type. Eventually, if this type of element is used more and more, a large stock of special tools accumulates. This was the condition in a large manufacturing plant which made a wide variety of machinery. One or more worm drives were used on every machine. No specific dimensional standards for worms, or for hobs for the worm gears, were available when the first of these products was designed, and no shop standards had been established for them. A few years ago, they found that they had to carry in stock about one hundred different hobs—all special tools—in order to meet their manufacturing and replacement needs. These worm drives ranged from small ones used to drive counters to larger machine drives, some of them transmitting up to about twenty-five horsepower. A survey of the situation, followed by a definite policy of standardization, reduced the variety of hobs to something less than one-half of the original number. In addition, the speed and load conditions on many of these worm drives were becoming more severe all the time, and much difficulty had been experienced because of heating and excessive wear on the product. A complete analysis was made of the contact and operating conditions on worm drives in general, and the standardized design was developed to take full advantage of all the information available. As a result, the standardized design gives much better service than any of the random designs had given. The hobs are still special tools as far as the tool manufacturer is concerned, since they are made to the detailed specifications of this company. The variety has been reduced, however, and all new designs of machines are made to use these standard hobs. The results today are not only a considerable reduction in the cost of manufacture and maintenance of these units (several thousand dollars a year), but also a great improvement in the operation of these elements in service.

Reference has been made to the use of standard parts for tools in the discussion of tool design. Where this practice has not been followed as completely as it might be, the additional cost of making some new special part for replacement in a worn jig or fixture should be called to the attention of the tool designer. If complete cost accounts are kept, this additional charge belongs to waste, and should be charged against the tool design.

Standardization of Parts and Surfaces

In every manufacturing plant, in the course of time, many similar parts are designed, each made for its particular use without reference to any similar element. If a critical study is made of such similar parts or surfaces, opportunities will often become apparent for making minor changes so that some of these parts with small differences can be made identical. For example, in one plant, about two hundred and fifty different parts were made on automatic screw machines. After two or three weeks of consideration, it was found possible to make minor changes so that the number of different screw machine parts was reduced to about one hundred and fifty. This gave the economy of a larger volume of production on a smaller variety of parts.

It is not sufficient to confine our attention to similar parts alone. We should also study the possibilities of making certain sizes and forms of similar surfaces identical. When these surfaces must cover a range of sizes, a definite shop standard should be developed for them. This has been done for such surfaces as tapped holes and threaded shoulders. It should be extended, as far as possible, to every other type of surface in common use in any plant. This is a task for individual plants. Such a procedure increases the percentage of standard tools and gages needed for production, even if they are only "shop standards," and reduces the number of special tools required for replacement and for starting the production of a new commodity.

It should not be necessary to debate the economy and utility of standardization in these specialized applications. Almost every one will agree in principle, but many will maintain that their problems are unique and that these principles do not apply to their particular case. They do use standards, that is, they use the general engineering standards that have been formulated and proved by others. The answer is that there are no "unique" cases. It is true that their work may involve unique problems, and that none of the general standards apply there. Nevertheless they can develop many special or unique standards of their own which will meet their unique requirements.

Introduction of More Effective Controls

Most conditions of manufacture which are unsatisfactory, all of which add to the expense of production, persist because of ignorance of the cause and effect of the many factors which influence them. The superintendent of a large factory once said to me, "All our production troubles can be divided into two classes: the obvious and the mysterious. The obvious we understand and we can correct them easily.

The mysterious we do not understand, and they are a continual headache!"

These "mysterious" troubles often require considerable study before they can be translated into the "obvious." Some may involve metallurgical talent to point the way to the solution; others may require complex analyses or several mechanical experiments before the answer is found. For example, a manufacturer of small tools was having considerable difficulty with excessive warping in one type of tool when it was hardened. It seemed probable that the structure of the steel before it was hardened should be of some definite condition. At the same time, it must be possible to machine the material readily or the cutting time in production would be increased, and this would add to the cost of manufacture. Experiments were made to find a structure and hardness of material that would meet the two conditions: easy to machine and with a minimum warpage in hardening. After two or three months of search, these conditions were established. Then more definite controls were introduced to insure that the material was put and kept in the proper condition before any machining on the tools was started.

Further, certain operations which may start correctly, may later produce unsatisfactory work which must be reworked or scrapped. An investigation may show that the trouble is the result of faults in the cutting tools. These tools may have been checked and found correct when they were first received and put into operation, but they may develop faults because of improper resharpening. In such cases, they must be checked after each resharpening. The natural tendency is to reduce all such inspection to a minimum; in case of doubt, leave it out. Additional checks, or controls, are added only when they are found to be absolutely necessary.

There is no end to the number of different conditions which must be guarded against. Many inspection methods may need to be changed to meet some unforeseen condition; additional controls must be introduced for many reasons. For example, one company making a very highly finished steel product that was often kept in stock for long periods of time found fingerprints etched on the surfaces of some of these parts underneath the protective coating of grease. The parts were carefully cleaned before greasing. On testing the perspiration of the different operators who greased and packed the parts, two of them were found to have definitely acid conditions. These operators were transferred to other jobs, while an acid test was given to all operators before they were assigned to this work.

Correction of Equipment

Although the condition of the equipment is kept under a reasonably close control by the routine inspection of the product, occasions arise when some "mysterious" trouble develops. This is particularly true when the requirements are severe. For example, a manufacturer of high-speed turbine reduction gear sets began to experience trouble in matching the helix angles of mating gears. This trouble started after the gear-cutting equipment had been in operation for two or three years. The mystery was that these differences were not always present; when they did occur, they were of a random nature. The gear-hobbing machine was carefully checked, some minor elements were re-adjusted, but the trouble continued. Then an analysis was made to determine, if possible, what elements of the machine and what conditions of these elements could cause the errors that were present in some of the product. It was finally decided that eccentric change gears to the lead screw could produce these results. The change gears were checked and found to be concentric, but their bores and the studs on which they had operated had worn considerably. The bores of the change gears were corrected to a common size, new bushings and studs were made to suit the change in the bores of the change gears, and the trouble disappeared.

As another example, an accurate tool room lathe was being tested for its performance in cutting lead screws and long micrometer screws. The lead screw of the lathe itself had been tested and had been found to be within the specified limits of accuracy. The screw which was cut on this lathe showed a definite error, much greater than that of the lead screw of the lathe. It was a long screw and the lead was definitely shorter than it should be. The direction of cutting on the machine was reversed, and the error on this sample screw was definitely long. The direction of the torsional deflection of the lead screw of the lathe when it was loaded introduced a measurable error in the product. To correct this condition, it was necessary to install on the lathe a new lead screw of larger diameter to reduce the amount of this torsional deflection.

Following Up Suggestions

If the members of the organization are definitely time- and cost-conscious, many suggestions will be made for the correction of details that will help the cost-reduction program. Pertinent suggestions are often received from unexpected sources. For example, tradition tells us that it was Mrs. Howe who suggested the placing of the eye of the needle near its point, a suggestion that made possible the practical development of the sewing machine.

These suggestions include chance remarks or comments of visitors to the plant, reports of members of the organization on visits to other plants, complaints of customers, and specific suggestions from the operators of the manufacturing equipment. Often a remark made in jest contains the germ of an idea which is worth serious consideration. A definite attempt should be made to collect every possible suggestion. These should be classified, considered, and followed up when they appear to have some immediate value. The others should be kept on file and reviewed from time to time. Frequently a suggestion that appears to have little merit today will prove to be of definite value later.

It is a great mistake to assume that all the brains of an organization repose in the heads of the administrative and engineering staffs. Collectively, as much or even more intelligence and wisdom may be found among members of the operating crews than is present at the top. Suggestions from operators who are continually on the job are valuable assets which should not be left dormant or frozen. A sincere, personal approach will do much to release them.

Reduction of Waste

Waste in industry includes the ineffective use of time, materials, abilities, or money anywhere in the organization. Thus whatever action makes more effective use of any of these elements tends to reduce waste. This, however, is a broader definition of the term than is usually accepted in the consideration of waste in a manufacturing plant. The attention is usually restricted to the saving of materials or their more effective use. Actually the specification of unnecessarily severe conditions of manufacture, which add unnecessary costs to the production of the commodity, is a definite waste in industry. Again, the use of obsolete and inadequate manufacturing equipment often increases the cost of production over that which could be realized by the use of modern machinery and methods; hence this is another item of waste in industry.

Mistakes in production, which cost additional effort to correct, may not appear in the cost accounts as items of waste, but they constitute an unnecessary addition to the cost of production. Many such items may be concealed in the overhead charges. Other items of waste appear directly as scrapped parts. To reduce this type of waste, the cooperative effort of every individual in the organization is needed. Many competitive plans have been devised to accomplish this by having definite campaigns started in the different departments to see which department can most greatly reduce its percentage of scrapped parts, material, and general overhead charges. The use of a more equitable

method of distributing the indirect charges helps to make apparent the conditions and places where material improvements can be made.

The collection and disposal of chips and other scrap material sometimes offer chances of their more effective use. They may be reconditioned and used again, either in the regular product or for the making of some by-product. Again, the careful segregation of the chips from some of the materials may result in obtaining a higher price for them as scrap metal. Or it may be that an investigation will often show that too much material is left for finishing, so that a change in the size of the casting, or forging, or bar stock will produce less chips to be collected and sold as scrap metal. Or the substitution of a forging for bar stock, or the purchase of material roughly cut to form at the mill by flame cutting will accomplish the same result, that is, less chips to be collected and sold for a much smaller price per pound than the original material cost.

In its broadest sense, all successful cost-reduction effort reduces waste.

Change of Materials

Conditions may change between the time when the material for any component part of the product is originally selected and the present. New materials may become available, new processes or new treatments for old materials may be developed which make the given material more suitable for use than before, and relative prices of different materials may change. All these and many other possible changes in conditions may make it advisable to change the materials used for certain component parts, sometimes to obtain better service from the part and sometimes to reduce the cost of production. This is a situation that requires continual watching.

Events may cause a scarcity of some types of materials. The event may be an extensive strike in the plants of the producers of these materials; it may be that new uses have been found for some materials and the supply is limited. Then substitute materials are essential.

The development of a wide variety of plastic materials is a comparatively recent occurrence. The initial cost of the material may be greater than that of some metals, but the lesser expense of forming it to shape and size, and the lesser amount of scrap in the form of chips, may make it more economical to use than the original material selected. Different plastics have a wide variety of physical characteristics, so that tests should be made of the behavior of such substitute materials under service conditions, if possible, before a definite change is made. For example, some automobile engine manufacturers changed

from sheet metal fingers in their distributors to plastic ones before the needed physical characteristics were definitely known. As a result, some cars were stalled by the roadside because of broken distributor fingers. After one such experience, one of my friends always carried spare parts of this type with him, and had occasion to use them. This was some years ago, and many of these shortcomings have now been corrected.

Accurate knowledge of the limitations of a product is more valuable to its producer than any other information. This applies particularly to the producers of materials. If we know where and when not to use it, we still have a large field of use for it and can avoid many troublesome experiences.

As another example, more attention is given today than ever before to the alloys of cast iron and their heat treatments. In one type of use, a heat-treated cast-iron alloy gives better service than a more expensive construction which uses hardened and ground steel. This does not mean that such cast-iron alloys are superior to hardened steel in all cases. In this particular case, the peculiar physical properties of the cast-iron alloy meet the actual service requirements more effectively than do the properties of hardened steel.

Parts Made Outside

With the progress of mass production, which involves the breaking down of the productive efforts into specialized fields, comes the rise of new plants which specialize in the production of some type of unit mechanism or of some type of component part serving several different plants and thus obtaining the economies of mass production. Such units, made in large quantities, can be bought much cheaper than they can be made in smaller quantities by the purchaser. Besides, many of these units, made as a specialty, are developed to a greater extent than they would have been if they had remained as a minor part of a larger program. In like manner, the technique and methods for producing these specialties receive more concentrated attention than they would have received otherwise, which leads to their more effective production.

It follows that a plant may start the production of a new commodity in moderate-sized lots. Many standard units may be used and purchased from outside manufacturers. All other special parts are made in the plant. As times goes on, the volume of production is increased. Soon the time may come when some of the special parts, in the larger quantities then needed, can be made more cheaply and better by some specialist plant which makes that type of part. This is another factor of cost reduction that should be continually watched.

Again, there are certain types of processes which have been developed as a specialty by outside organizations, such as die casting. This is primarily a process for large quantity production. Very often, in order to make the best use of these facilities, it is necessary to redesign the product. Several individual parts may be combined into a single die casting. To fit this design to the process and to retain all the functional advantages of the product, this work of redesign requires the cooperative effort of men from both organizations. This is true of all specialized processes. When the volume of production is great enough, such special equipment may be purchased and installed in a specialized department of the plant, and these parts may be made by the user. Even so it is not always certain that this will give greater economy. The specialized plant still has the advantage of an established technique and long and wide experience, factors which cannot be bought or transferred in part from one plant to another.

Another occasion for outside production assistance arises when there is a temporary demand for a more than normal volume of production. The excess production will not be permanent and the manufacturer is not justified in enlarging his plant. Under these conditions, the "farming out" of some of the manufacturing may be advisable. The special equipment available is then sent to the outside contractor, and technical help and supervision should be included. In effect, this contractor's plant is a temporary extension of the regular plant, and all the controls which have been found necessary in the regular plant should be extended to cover the outside work.

We generally assume that the outside plant can do a better job than we can do ourselves. This may be due probably to our inherent modesty. Hence we are apt to be more demanding and critical of the parts machined outside than we are of the parts which we machine ourselves. Or it may be that we have more sympathy for our own troubles and shortcomings than we have for those of another. The result is the same. We ought to judge and treat the parts made for us by an outside plant just as we do those of our own production.

Improvement of Working Conditions

Favorable working conditions are always a help to effective production. Two phases of these conditions must be considered: first, those which influence the operators, and second, those which influence the processes. There are certain minimum conditions which must be met if we are to operate with reasonable effectiveness; further improvements in these conditions increase the effectiveness of operation.

The operator must have light, heat, and ventilation. If any of these

conditions are so poor that they affect the health or comfort of the operators, they are reflected in a decreased output or lower quality of product. As they are improved until they reach an optimum, the chances of obtaining an improved output, both in quality and quantity, are greatly increased. Improved lighting, for example, does not necessarily mean an increased quantity of light—the existing quantity of light may be arranged or directed in a more effective manner. This problem of illumination has become a specialized study in itself, and significant advances have been made towards the more effective illumination of many types of operations.

Noise also has its influence on working conditions and output. Tests have indicated that a reduction in the noise level and the elimination or reduction of the intensity of certain types of sounds improve the working conditions for the operators. This has forced the designers and manufacturers of machinery to give more thought and effort to the production of quieter machines.

Personal feelings and relations have a profound influence on the effectiveness of the personnel. The general atmosphere of a department, in this respect, has a decided influence on the effectiveness of the working conditions. No workman is at his best if he has a personal grievance, either real or fancied, against other members of his group. This general atmosphere often extends throughout a given organization. Every organization has a definite and individual personality which is apparent in the behavior of all members of it, from the office boy to the president. It is my own experience that when visiting a plant or office for the first time, I subconsciously form an opinion of the organization from the character of my reception by the office boy or person at the reception desk, and this first impression is seldom changed by my further acquaintance there.

With regard to the processes, there are certain minimum working conditions which must be maintained for effective production. Sometimes humidity is important. If we must depend upon the weather, we shall have a varying quality of product. In extreme cases, we may not be able to operate at all. To improve such conditions, we can install air conditioning. This will make possible the continuous production of a uniform quality of product regardless of the weather. At other times temperature is important because the temperature must be held within close limits. At still other times, there must be a uniform temperature throughout the working period, but the actual temperature may vary widely in different periods. Under such conditions, the installation of temperature control increases the chances of effective production.

The presence of dust or grit in the air may be detrimental to the

performance of some processes. To minimize this, exhaust systems may be installed to carry it away from the place where it is created. Similar exhaust systems are employed to remove objectionable fumes or gases from the working spaces. These may be supplemented by the washing and conditioning of the air. Some laboratories and factories, such as plants making silverware, are often set on a plot surrounded by shrubbery and grass lawns. These are not purely for ornamental purposes since the surroundings reduce the amount of dust about the plant. Excessive dust in such plants not only increases the amount of wear on the tools but also spoils the surface finish of the manufactured parts. This, in turn, increases the amount of polishing needed before the product is completed.

As an example, a group of men in a plant wished to make a tennis court to use during the noon hour and in the evenings after working hours. There was plenty of land around the plant, and one corner of it, away from the factory buildings, was suggested as a good site. A club was organized and enough money collected to make the court. One of the officials of the plant was interested in the project and was a member of the club. He suggested that the court be moved to a space between two wings of the plant because it was nearer, the space was sufficient, and it would need only a single fence at one end, and thus reduce the assessment on each member. Permission was granted, and the tennis court was accordingly made between the two wings of the plant. The punch press department was located on the ground floor of one of these wings. After the grass outside the windows had been replaced by the clay surface of the tennis court, the cost of maintenance of the punch press tools was nearly doubled. These increased costs did not receive any attention until about four months after the tennis court had been made. When it became evident that the dust from the clay surface of the court was responsible for the excessive wear of the tools, a new court was made, at the expense of the company, at a site away from the factory buildings, and the sod was restored between the two wings of the factory.

Education and Training of Operators

Much waste in industry is the result of mistakes most of which are caused by carelessness, lack of skill, or ignorance. The only effective way to reduce the number and the gravity of such mistakes is to educate the personnel. This subject has already been discussed in Chapter VII. It is mentioned again here to emphasize the fact that all such efforts are definite and valuable steps toward the reduction of waste and costs of production.

The foregoing items do not include all those which need consideration for the elimination of waste and the reduction of costs. The very geographical location of the manufacturing plant may introduce factors of waste. If a plant is located where all its raw materials must be shipped in from distant points, and all or most of its finished products must be shipped away to distant places, then the shipping costs involved may be a major item of waste. When a plant is located near the source of supply of its raw materials, or near its principal markets, or between the source of supply of materials and its major markets, the relative cost of shipping is low, hence this item of waste is reduced or eliminated. But geographical location alone is not the controlling factor. We must also consider the climatic conditions as they affect the personnel and the processes, the living conditions for the personnel, the type and number of operators available there, and other facilities such as sources of power. We must also consider the types of product which are manufactured. These may be divided roughly into two categories: first, the technique products, and second, the tonnage products. The technique products are those for which the skill and workmanship required are the principal items of the cost of production. The tonnage products are those for which the materials used are the most important items of cost. Geographical location is most important to the tonnage product made in large quantities. A small plant making a tonnage product to fill local needs may be located near its market. The location of a technique product industry is often determined by the existence of a large group of skilled workmen who live in a particular locality.

SECTION 3. SUPPORTING ACTIVITIES

CHAPTER X

STANDARDIZATION

Engineering standardization is, as noted before, an attempt to reduce to routine as many of the details of engineering problems as possible. Without definite encouragement, and in the absence of a fixed policy, instinctive attempts are always being made by individuals and groups in an effort to reduce to order a large amount of detail work which must be repeatedly performed. These efforts may not be recognized as attempts at standardization; they may be considered as the development of a system. Actually they are instinctive moves towards standardization.

If a program of standardization is to be carried through effectively, it must be supported as a definite policy of the management. It involves every branch of the production organization and should not be dependent on any single branch. Too often it is considered only as a policy of design and is therefore relegated to a subordinate place among many other functions of design. This concept restricts the field of its application, and prevents its full potential benefits from being realized. Standardization should be one of the active policies of management, and can be directed and administered best by a standards engineer who is an integral part of the staff of the general manager or other directing head of the organization.

The question may be raised as to the responsibilities of such a standards engineer. Should he be a man capable of formulating the standards as their need becomes apparent, or should he direct and coordinate the activities of others? He should promote, coordinate, and direct such activities. The formulation of a particular standard should be in the hands of all interested parties; any group which is affected by the adoption and operation of a standard should have a part in its development. The standard or routine adopted should represent the solution that best meets the requirements of all parties at the time it is accepted. Provision must be made for the revision of a standard whenever it can be improved or amplified, and all standards which are adopted should be reviewed periodically.

There are many classes of standards to be considered. For the pur-

poses of discussion, they are divided into four groups: (*a*) shop standards, (*b*) manufacturers' standards, (*c*) trade standards, and (*d*) general engineering standards.

Shop Standards

Standards for use in a particular shop or plant should include not only all specifications which have been developed by other groups and are of value to the plant, but also many special ones which the plant itself must develop to meet its peculiar needs. These standards and specifications should cover, as fully as possible, all six following categories: (*a*) materials and supplies, (*b*) processes, (*c*) cutting tools and elements of special equipment, (*d*) elements of production machinery, (*e*) construction or design elements of product, and (*f*) elementary parts and surfaces of product.

Shop Standards for Materials and Supplies

Many of these standards will be selected from available manufacturers' and general engineering specifications. For these, the major problem of the shop's standardization activities will be the selection of definite materials for specific types of use, and the reduction of the number of different materials to a minimum. In addition, standard sizes of bars, sheets, tubes, and other forms of raw materials should be selected, and the variety of these sizes should be kept to a minimum. These sizes and forms, as far as possible, should be restricted to those normally carried in stock by the manufacturer. The use of stock sizes, however, is not always possible; some special ones may be needed. When this is true, it is best to try to keep the number of such custom-made materials to a minimum; that is, to use such materials in as many different places as possible when special sizes are needed, or to re-arrange the design of the product to combine as many of such specifications as is practical into one specification.

The specifications for a material can be given in one of two ways: first, in terms of its chemical composition, structure and conventional physical properties; second, in terms of some service or use test. One or the other should be given, but not both. If some effective service test is possible which will prove the material for its quality in the particular service it must render, that test should be the measure of quality. Then the producer of that material can devote the major part of his efforts to obtaining and improving those characteristics of his material which will best meet the specified service conditions. Service tests of this sort may be the result of considerable experimental work at the plant or elsewhere. When a test has conclusively proved itself

to be effective for a given purpose, then it can be used as the means of specifying the required quality of the material and as the test of this quality.

For example, one company which used many high-speed cams in its product became convinced that many of the special physical properties of the phenolic laminated materials (Bakelite) should be valuable for such high-speed cams. Extensive experimental work on this problem was done in cooperation with one manufacturer of this type of material. In the course of these experiments, it was found that a surface endurance test, made by running a test roll of this material against another roll made of metal under different loads and at different speeds, gave an accurate forecast of the behavior of these materials when they were used as cams. The speed of running was an important factor here because this type of material has high internal friction, low-heat conductivity, and a loss of strength with increasing temperature. Eventually a satisfactory material was developed for this purpose which would carry a certain load at a certain speed for about four million cycles before the surface failed. This test was adopted as the specification for this material. Sample rolls are made from new lots of this material and tested to insure that the quality is maintained. Other makers of this same general type of material submit proposals, from time to time, to furnish their products for this use. They are asked to submit test rolls of their material for trial. If these test rolls meet requirements, or show better results on these tests than the results obtained from the materials then used for the purpose, their proposals will receive favorable consideration. If their materials will not meet the conditions of these tests, their proposals will not be given any consideration. As a matter of general interest, none of the competitive materials to date have stood up longer than about two million cycles under these test conditions. Although all such materials have much in common, the supplier who cooperated in the original experimental work has been able to develop his processes and technique to meet these peculiar conditions because of the experience he got during the progress of the original tests.

Shop standards for materials and supplies should not be restricted to the raw materials which are used to construct the product. All expendible supplies should be studied, and definite shop standards should be adopted or developed for any type of such supplies which is purchased frequently or in an appreciable quantity. This applies to printed forms and other office supplies, cleaning compounds and soap powders, lubricants and cutting compounds, belts and belt fasteners, and paints, varnishes, and lacquers which are used to finish the product, as well as to nails, lumber, and boxes which are used to case the product for ship-

ment. All specifications should try to define the materials required in terms of actual needs. Exacting specifications do more harm than good. All specifications should be restricted to the fewest possible needs that will insure an adequate material for the particular use and need.

Standard Shop Processes

Most of the processes used in a plant tend to develop, from their continued use, into routine or standard processes. Written specifications or instructions about them may not exist, but such standards actually do exist in the minds and habits of the shop group. Modifications of these practices are the result of experience, that is, when trouble is met on some operation, variations from routine practice are tried until some solution for that trouble is found. It is a good plan to record as much of this experience as possible so that many of these troublesome operations can be anticipated or avoided. For example, a record should be kept of speeds and feeds used on all types of cutting operations on the various materials and machines, together with the different types of cutting tools employed. From this information, a standard condition for the speed and feed can be established for each type of operation, equipment, material, and type of cutting tool. Departures from the normal condition should be studied to determine why they are needed, since the information is a valuable guide to the selection of the speeds and feeds for any such operation, either normal or exceptional. Much information on this subject will be found in shop handbooks, machinery manufacturers' instruction books, and published data of tests on the cutting of metals. Even so, each individual plant should check this information against its own experience, and develop its own shop handbook or data sheets to fit its own plant, product, and requirements.

Many plants making specialized products find it necessary to develop special processes and equipment to meet their own unique production problems. Some of these plants protect their product with patents, but do not attempt to get patents on any of their special processes or special equipment. Definite written specifications for their practices and processes will then serve a double purpose: it will reduce much of their shop practice to an orderly routine; because of the definite record of prior use, it will be some protection against possible suits for infringements of patents issued later to other persons. For example, one large organization which makes a highly specialized line of products and which does not attempt to obtain patents on the processes they have developed for their own use is called upon from time to time to defend infringement suits on processes which they have used

for many years before the patent in question was issued. A sworn statement to the effect that this process had been used by them for many years prior to the issue of the patent is not considered by the court as adequate evidence of priority. A written record of the process and instructions for its application, dated early enough or supported by dated orders for the special equipment, etc., would be considered as much better evidence of priority. To meet this situation, the organization has prepared a complete record of its production processes, including the history of development of each, its dates of changes and improvements, and details of its application. These records are kept up to date as improvements are made or as new developments are begun.

Unexpected problems arise in all phases of production, particularly when we introduce some new method. For example, multiple-spindle, power-driven screwdrivers were introduced in one plant to increase the rate of production at the assembly of some small units that were made in enormous quantities. At the first trials of this equipment, many of the small screws broke as they were being screwed down. After considerable study, it was finally determined that these screws needed some lubricant because of the speed at which they were driven. It was not possible to use oil or grease as this would affect the performance of the product. At last a process was developed which consisted of mounting the screws in a simple frame, spraying the threads with a special lacquer, and then burning the lacquer. This process left a sufficient deposit to act as a lubricant on the threads so that the screws did not break at assembly. Specifications and instructions for this process were then prepared, and it became another standard shop process for use here and in several similar places.

Shop Standards for Tools

The need and value of shop standards for tools and for elements of work-holding devices have already been pointed out in the discussion of tool design. Many of the shop standards for cutting tools can be selected from the catalogues of the manufacturers of small tools. Here the major problem is to keep the variety of such tools to a minimum. This requires the cooperation of the production design group, because the sizes and forms of the surfaces on the parts of the product must be held to a minimum variety, if we are to keep the number of different cutting tools to a minimum. However, when the possibilities of reduction of variety in this feature are overlooked by the production design group, the study of the different cutting tools required to meet the

production operations will make evident many chances of reducing their variety by minor changes in the production design.

Every plant always has some individual problems which require the use of cutting tools other than those carried in stock by the small tool manufacturer. Some of these tools may be required to machine some surface of standard size and form, but with a surface which must be plated, for example, and the plated surface must meet the specifications of size and form. Here the cutting tool must be made of different size to allow for the thickness of the plating. Different kinds of protective coatings require different thicknesses, hence either a uniform type of protective coating must be adopted to keep the variety of these special tools to a minimum or a wider variety of special tools will be needed. Again, the method of depositing this coating will have an influence on the uniformity of the thickness over the different parts of the specific surface. If the thickness of the coating varies, then the form of the cutting tool must be changed accordingly. If differences in this respect result from using different methods of depositing or applying the protective coating, then again we must choose between the use of a single method with the lesser variety of tools or the use of the different methods with the greater variety of cutting tools.

Here is another type of special requirements for tools. In a plant making many sheet metal parts containing tapped holes of various diameters, the use of standard screw threads and taps did not prove satisfactory. The standard screw threads have a coarser pitch with increasing diameters, whereas the thickness of the sheet metal, which means the thickness of the nut in this case, is constant. Here it was necessary to use a constant pitch (forty threads per inch) on all diameters of screw threads in order to have a sufficient number of turns of the thread in the thickness of the sheet metal. To reduce the variety of taps and dies to a minimum, all screw threads from number 4 to number 10 in size were made with forty threads per inch, even though many of the tapped holes were made in castings and screw machine parts where the regular series of standard screw threads could have been used.

Many of the elementary parts of work-holding devices can also be standardized to advantage. Here again, many of these items such as drill bushings, blank vise jaws, handles and locking devices, and elements of sheet metal working tools, may be selected from handbooks and manufacturers' catalogues. In addition, many features of design of such equipment can be adopted as standard design practice. Many other elements may be designed to suit each plant's particular needs. Some of these may be carried in stock as finished parts, whereas others

may be partly finished as standard blanks from which to make the special parts required. In this last case, the economies of a larger volume of production are obtained on the roughing operations, even though each part must be finished as an individual and special item.

In many plants, where such standard blanks are carried in stock, a printed form on tracing cloth or tracing paper is provided for the tool design department. These forms give all the dimensions for the parts except the special ones which must be added to complete the drawing. With these, the draftsman's task is reduced to filling in the special information needed for each different case. This practice is carried even farther in some plants, and includes similar printed drawings of the designs of many types of simple work-holding devices. These printed designs are altered or completed as may be required in each particular case. This practice is possible only when many of the elements of such types of equipment have been standardized.

Standard Elements of Production Machinery

To a large extent manufacturing plants are at the mercy of the machine tool builders as regards the effectiveness of their efforts to have uniform conditions on similar sizes and types of the productive machinery. When a specific type of machine is urgently needed, we must take what we can get. Variations in spindle-nose design, size and position of the T-slots on the work tables, work-size capacity and cutting range between similar types of productive equipment made by different manufacturers of machinery must be accepted as inevitable. These variations, in their turn, defeat attempts to obtain effective standardization of some of the elements of special work-holding devices and other accessory equipment, a task which would otherwise be possible. Under such conditions, each time we equip these machines for the manufacture of a new product, we must spend more than would otherwise be necessary to make the accessories. This situation, in the past, has often forced the purchaser of such machinery to buy his new equipment as it is needed to meet the demands of an increasing rate of production from the same maker who sold him his original machines. This, in its turn, was an incentive to the manufacturer of machinery to make such elements of his product different from those of his competitors so as to retain his customers, or rather to make it more difficult for his competitors to sell to his customers.

The smaller manufacturers, if they wish to realize the economies of this feature of tool standardization, must either restrict their sources of supply of machinery to the makers of their existing machine tool equipment or remachine these elements of their machinery to some

common standard. In any event, the dimensions of all those elements of their machines to which their special equipment must be fitted should be a matter of record for the use of the tool designer.

Some of the larger manufacturing organizations have developed their own shop standards for these elements of the machine tools. These standards are included in the purchase specifications for new machine equipment, and the machine tool manufacturer must meet them, even though they are different from his regular practice, or lose the order. At the present time, efforts are being made to formulate general engineering standards for these elements of machine tools, and considerable progress is being made.

Shop Standard Practices of Design

Much unnecessary time is spent in the design of a new product because of the lack of standard shop practices of design. Every similar product has many similar elements, although they may be of different sizes and arranged in many different ways. The effort should be made to break down the design of the product into the different units of construction, and to establish some standard type of design for as many of such units as possible. These might be selected from the variety that has been used in the past, on the basis of its over-all effectiveness. This includes service performance, reliability or stamina, and ease of production. The best of these should be adopted as the standard construction. Specific design projects should use these standard constructions. Attempts to improve them should be handled as definite development projects, and not be combined with the problem of specific design.

These standards include the use of specific combinations of materials for specific purposes, as well as the geometrical forms of various units. They also include standard clearance ratios or specific allowances for different conditions of fit. These are dependent on working loads, speeds, and the particular combination of material used. Each type of product has its unique problems, and most of these standards must be developed at each individual plant to suit its own needs. Far more of this design can be reduced to routine than is generally realized. By so doing, the manufacturer can obtain the benefits of a consistent performance of the product, steady and progressive improvement of the product, reduction of the cost of design, and reduction of the cost of manufacture.

For example, tests on the performance of bearings in one plant, with different types of lubrication such as wick feed, oil cup, ring oiling, and positive flow of oil, showed that with a given combination of materials and a given clearance ratio, an annular groove in the middle of the

bearing gave the best results. Several different clearance ratios and several different types of oil grooves were also tried, but there was one definite combination of conditions that gave the best results for all methods of lubrication with oil. This specific combination has been established as the standard practice for design and must be used until something better can be developed.

Shop Standard Parts and Elementary Surfaces

The majority of the usual shop standards are limited to this phase of standard parts and surfaces. It is unfortunate that most of these standards are selected from those found in handbooks, manufacturers' catalogues, and other published standards. Even here, every effort should be made to reduce the variety to a minimum. This subject has already been considered in the discussion of standard tools and production design. As noted before, the production design itself is a process of making each component part of the product a shop standard part.

Many references have been made to the standards material which may be found in handbooks, manufacturers' catalogues, and other published standards. Such publications should be kept on file for general reference, but these complete publications should not be used indiscriminately because their range is greater than that needed in any one plant. A shop standards handbook or file should be built up by selection from all available sources, and should include all special shop standards which have been developed by the plant itself. Only in this way can we be certain that everyone who is called upon to specify the use of a standard will select the same one.

Manufacturers' Standards

The manufacturers' standards include all items in their catalogues or handbooks. Many of these are carried in stock. These standards may be divided into four general groups: (*a*) machinery and accessories, (*b*) materials, (*c*) assembled units for product, and (*d*) finished component parts. Some of these standards conform to trade and general engineering standards; others are specialties which have been developed by the particular manufacturing organization which sells them.

Standard Machinery and Accessories

Every machine tool manufacturer issues catalogues and circulars describing his product and indicating the work-size capacity and range of operating speeds and feeds. Some manufacturers of unusual or intricate machines also publish an instruction book which gives detailed infor-

mation for setting up and adjusting and operating these machines. These publications often give information about the design of special tools for the machines as well as a list and description of the accessories which are available from stock. Other manufacturers send condensed operating instruction to their customers. For the more common types of machine tools such as lathes, planers, shapers, and drill presses no special operating instructions are prepared unless there are some new or unusual controls or other features which must be explained. Several machine tool manufacturers issue sheets of performance data, sometimes as advertisements in magazines, and sometimes as individual sheets to be assembled in a binder, sheets which give detailed information about the tooling, operation time, speeds and feeds of cutting, and accuracy attained on specific production operations. Even so, each manufacturer should check the performance of all equipment in his own plant as it works on his own product. From this information, he should develop the specifications of his own standard shop practice.

Many accessories are made by the machine tool manufacturer for use on his own machines. Many others are produced by independent plants, some of which may concentrate their efforts on one type of product such as chucks, vises, tapping attachments, grinding attachments, die sets, and sub-press die frames. These are described in circulars or catalogues which give their working capacity and the dimensions of those elements which fit the machine, or the tool, or the work. Sometimes an adapter is needed to connect the device to the machine. This may be made by the manufacturer of the accessory or by the manufacturing plant which uses it. Here also, those accessories which are actually used in any plant should be listed, and every effort should be made to reduce their variety to a minimum.

Tools and Measuring Instruments

Some small-tool manufacturers produce a wide variety of cutting tools, whereas others concentrate on the production of a single type, such as drills and reamers, taps and dies, and milling cutters. In addition, some makers of specialized machine tool equipment also make the special type of cutting tool required on their own machines. All issue catalogues or circulars giving specific information about these cutting tools, and listing the sizes and forms which are "regular" or carried in stock. In addition, there are several types of cutting tools which are used to finish machine elements which have not been generally standardized, such as hobs for worm gears and formed tools of many types. These catalogues usually specify the nature of the infor-

mation which must be supplied by the customer so that these special tools can be made correctly.

Many of the stock cutting tools have been developed to meet the requirements of published trade standards and general engineering standards. Others are based on the customer demand for certain types and sizes of cutting tools. Still others have been developed by the small-tool manufacturer to meet some apparent need, or to improve upon some other standard tools.

Developments in cutting tools have forced many improvements upon the machine tools. For example, the introduction of materials for cutting tools which will stand up under heavier cuts and faster cutting speeds than tools made of ordinary tool steel has made it necessary for the machine tool builders to make heavier and more rigid machines with faster operating speeds. Now some of these newer standard cutting tools cannot be used to their full advantage on some of the older and lighter machine tools. Hence our shop standards for cutting tools should be selected from these manufacturers' standards, and due account should be taken of the equipment on which they will be used when the selection is made. A more expensive high-speed tool is of questionable value for use on an old machine which cannot stand up under the speeds and feeds which the tool can take.

The measuring tools can be divided into two classes: the general purpose measuring tools such as micrometers, calipers, steel scales, and vernier calipers, and the single purpose measuring tools or gages. Many types of general purpose measuring tools have been developed by different manufacturers. A large variety of types of gages have also been developed by the gage manufacturer, many of them for general use in the machine shop. The sizes of such gages which are carried in stock have been based largely upon customer demand. If enough orders are continually coming in from several customers for the same size and type of gage, such gages are made in lots, carried in stock, and listed as a regular size.

Many other gages carried in stock are based upon the specifications of some published trade standard or general engineering standard, provided that the customer demand is large enough to make it worth while. In some cases, one particular gage maker will make and stock gages for some particular trade standard, generally because this gage maker cooperated with the trade association in the original formulation of the standard and thus got started first. If the volume of business here is limited, it is not worth while for other gage makers to stock these items, although they would make them as special gages. Hence the stock lists of different gage manufacturers, although they

have many items in common, are not identical throughout. Such lists from several gage makers are needed when sizes and forms of the shop standard list of gages is compiled.

Standard Materials

Most producers of metals and alloys publish handbooks which list the sizes and forms in which their material is furnished, the physical properties of the materials, and sample test specifications. Many of these materials are made to conform to the specifications established by the general engineering standards groups. Some have been developed by the individual producer to meet the demands of their customers, or as a result of research or experimental work undertaken to improve some of the physical properties of the materials. A few of these developments have been patented, and as a patented product cannot be accepted as a general engineering standard unless satisfactory licensing arrangements can be made, these patented materials will seldom be found listed with the other general engineering standards for materials.

The individual production plant must select for itself the specific materials to use in its own product. As noted before, as many as possible of such materials should be selected from available stock or standard materials. Even so, if a specific service test will prove the material for its specific use, that service test should be substituted for the standard test procedure. In all cases where a material must meet some service condition that departs from the ordinary structural or operating applications of any of these materials, the cooperation of the organization which produces the material is always of great value. Perhaps some other standard material will meet the situation better than the material originally selected can meet it. Perhaps a special heat treatment will add to the essential physical property, or some slight change in the composition of some otherwise standard material will give the best results. For example, a certain automatic machine frequently broke down in operation because of accidental overloads. When this occurred, an expensive hardened-steel cam, roller, and follower arm were ruined, and had to be replaced. The suggestion was made that if a suitable bronze could be found for use in making the cam roll, to replace the hardened and ground-steel roll, when an accidental overload was imposed, the cam roll would be crushed, but the cam and the follower arm might be saved. This bronze, however, must have a high enough surface endurance limit to carry the normal load without excessive wear. Standard bronze alloys were tried and found wanting. Then the metallurgist of one of the bronze companies was called in, and the situa-

tion was carefully explained to him. In a couple of months he had found the solution. This was a special bronze alloy with a special treatment which had a sufficient load-carrying capacity for the normal load, but which would crush under the overload without injuring the cam or follower arm. A suitable load test was prescribed which formed the entire specification for this material.

Many materials other than metals must be purchased by every production organization. For the majority of such materials, trade standards only are generally available. Many of these are sold under brand names, and definite specifications of either their compositions or measurable "use" factors are conspicuous by their absence. General claims of "better than the best of the best" are common, but their qualities are seldom given in terms that can be definitely checked or measured. It is a good practice for each plant to formulate its own specifications for such materials in terms of definite service or use tests.

Assembled Units for Product

It must be realized that the finished product of one manufacturing organization may be a part of the raw material or a unit of the product of other production plants. As noted before, new manufacturing industries are constantly organized to produce some single type of specialty. These companies issue catalogues or handbooks for the use of their customers to help them in the selection of the best unit for their product. Many of them also have sales engineers who will work with the product designers, and help them to design their product so as to adapt it to use these specialized units to best advantage. They will also recommend the specific size or type of unit to use.

The information given about these assembled units generally includes the dimensions of all elements that affect their connection and mounting, or installation, and some measure of their working capacity at different speeds, or other factors of operation. The capacities listed are based upon some definite condition of use, often laboratory test conditions. These capacities must be modified to suit the actual conditions of use, either as determined by experiment or on the basis of past experience. In some extreme cases, the rated capacity of the unit must be two or three times as great as the actual average capacity required.

Such units include electric motors, controls, gear-reduction sets, many units used in the construction of automobiles, valves, and ball and roller bearings. In the case of ball bearings, the rated capacity is usually based on a specific average length of life under a given load at a specified speed. The rated loads are radial ones. With a greater load, the length of life will be decreased; with a lighter load, the length of

life will be increased. With combined radial and axial loads, a value is computed for the equivalent radial load. The manufacturers' handbooks generally give data for computing these conditions. Their sales engineers are also available to assist in checking these conditions. Nevertheless the production organization must rely largely on its own experience with these and all other purchased units to determine what will be adequate for use in its own product.

Finished Component Parts

Many manufacturing organizations concentrate on the production of a single type of finished component part such as upset or swaged products; screws, bolts, nuts, and other threaded products; lock washers and other locking devices; pipe fittings; and many other specialties. Some are made to meet the specifications of trade and general engineering standards; others have been designed by the manufacturers themselves. In addition, these companies often make a wide variety of custom-made parts to the purchasers' specifications. Close cooperation with these manufacturers of specialties in the early stages of the production design is always of great advantage. Minor changes in design will often save the expense of many special tools.

Trade Standards

Many trade standards have been adopted by various trade associations for use in their own specific industry. Some of these were first developed in some individual plant, and were later adopted by the trade association for general use in the industry. Other trade standards have been formulated by special committees organized for the purpose of developing some specific standard, and adopted by the trade association.

There are two general types of trade associations: first, groups of manufacturers or producers of commodities used in a specific industry; second, groups of operators or users of these commodities in a common industry. The majority of these trade associations belong to the first type. Practically all include standardization as one of their principal activities. Some of these industrial associations operate a testing laboratory where samples of their product are checked from time to time to insure that it meets the prescribed standards. At the present time, there are nearly two hundred of such trade associations in the United States.

Information about these trade standards is published in circulars issued by the trade associations, and much of this information has been copied in various engineers' and shop handbooks. Most of the trade

standards have been developed by the producers of the material and naturally the principal consideration has been given here to the economy of manufacture. These trade standards can be separated into three general groups: (*a*) material specifications, (*b*) trade practices, and (*c*) standard products.

Material Specifications

Most of the material specifications adopted by a trade association are selected from existing standards to cover the needs of their manufacturing processes and their products. These specifications may cover the composition and physical properties of the raw materials, or the form in which it is furnished to them such as plates and forgings, or both. In some cases, certain modifications are made to standard specifications in order that the material may be better suited to their use. Such modifications may include a particular heat treatment in order to obtain a definite structure of the metal, or a closer limit on some elements of the composition of the material. In many ways it is the same procedure that an individual manufacturing plant should follow in selecting its own shop standards for materials.

For consumer groups, their material specifications are selected to obtain the greatest service from the materials in their specific uses, with less interest in the problems of forming and shaping the material into the finished product, except as this factor is controlled by their sources of supply. However if the consumer group uses a sufficient volume of materials, and is insistent, and all ask for the same thing, they can obtain anything they need within reasonably practical limits.

Trade Practices

The common practices of a trade association, adopted formally or by tacit consent, cover a wide range of business, industrial, and engineering activities. Here we are interested only in the engineering practices. Most of these relate to test procedures and to details of construction or to practices on custom-made products which will be used when the customer's specifications are incomplete or indefinite about these details. For example, certain clearances on bores, sizes of keyways, and other clearances and tolerances are adopted as standard practice for use in the absence of definite specifications from the customer. Specific trade terms may also be defined. Standard proportions for units of construction may be developed. Specific test procedures of many kinds are adopted as standard practice. Standard load or work-capacity ratings may be established. It must be realized that any standard rating is not a definite measure of the actual or ultimate capacity of the

unit. Every individual unit has its own ultimate capacity, and these will vary between different similar units. These ratings may be based upon a minimum value which must be met by all such units. They may be based upon the average capacity of a group of similar units. Here some units may have less than the average or rated capacity, whereas others have more capacity than the rated one. Most of such ratings are based upon test data which has been carefully analyzed and put into good engineering form. Some methods of establishing the rating are arbitrary and have been developed primarily to impress the purchasing agents. These have little or no relation to a measure of the service which they are supposed to give. A "rating" value of this sort means little or nothing until it has been definitely checked against actual performance or until the method used to establish this value has been carefully analyzed to determine its probable meaning.

Trade Standard Products

The products of trade associations which are made to conform to adopted standards consist of commodities used in the particular industries of these associations. Some of these cover standard dimensions and forms that affect the connection of different units; some are specifications of physical properties of fabricated products and include the adopted test procedure to be used to check these properties; some are of the nature of safety codes and include a definite test procedure to insure this safety; and some are standards or practices of construction. Many of these standards are published in handbooks which have been prepared for a particular industry.

For example, the trade standards for pipes and fittings include dimensional specifications of the assembling or connecting elements, such as pipe threads, stuffing boxes, and bolted flanges. They also include specifications of the diameters of pipes, thicknesses of walls, and dimensions of connecting units such as couplings and unions. A maximum pressure test for different types of product may be specified and tested by hydraulic pressure.

Again, the electric fixture industry has developed its own standards for the sizes and forms of its connecting elements. The electrical appliance industry has developed safety codes for the insulation of its products and has sometimes prescribed definite tests to check these conditions. In addition, they support a central testing laboratory to prove this quality of the product of their member companies.

The bolt, nut, and rivet industry has a large number of its own standards for upset and threaded products, including all the general engineering standards that apply to this product. The steel construction

industry has many standard items of construction such as the location and spacing of rivets and the detailed design of many types of connections.

There is no reason why any other industry which may have use for some of these trade standards should not use them, even for uses outside of the field for which they were originally developed. Thus it will get the benefit of the established practice without having to develop something different for its own use.

General Engineering Standards

All the national engineering societies accept the task of standardization as an integral part of their activities to advance the state of the art in which their major interests lie. Each organization has its own procedure for this work, but all organize special committees to formulate each specific standard or each different type of standard. Inevitably there are some projects of one organization where some details overlap the standardization projects of some other. For the most part, when such overlapping efforts become known, the attempt is made to cooperate, either informally by correspondence or formally by the appointment of a conference group or joint committee made up of members from the two committees. Occasionally, however, it has not become known until after the publication of conflicting standards that committees of different engineering societies were working on overlapping projects. To overcome this condition, and to provide a clearing house through which all general engineering standardization projects may pass, the American Standards Association was organized.

American Standards Association

This organization does not formulate or approve the technical soundness of any standard. Its major object is to see that all interested parties are represented on the sectional committee that is organized to develop the standard, and that the standard represents the best judgment of the entire group by receiving a substantially unanimous approval of all members of the sectional committee. The sectional committee is organized by one or more sponsors, who must approve the work of the committees by their existing standardization procedure. Current news of the progress of this work of standardization is published monthly in *Industrial Standardization*, a publication issued by the American Standards Association. Each year a new catalogue is issued, listing all the standards which have been approved in all fields, and giving the prices of each standards publication. At the present

time, about four hundred of these standards have been approved. They cover a wide field of industrial applications and safety codes.

A comprehensive article entitled "The Role of Standards in the System of Free Enterprise" by Howard Coonley and P. G. Agnew was published in the April, 1941, issue of *Industrial Standardization.* This article gives an excellent summary of this subject of standardization, including a description of the work of the American Standards Association in this field. All parts of the article which bear on the problem of production engineering are quoted as follows.

The importance of standardization in the national economy and as an instrument for the solution of innumerable problems and difficulties which would otherwise grow into industrial, social, and political controversies and dislocations, and therefore liable to become matters of legal regulation, is not generally understood. While it is generally recognized that standardization is essential to mass production, and that it has been extensively used for this purpose by many American manufacturers, most business leaders apparently regard it as a purely technical matter which has only minor significance. Hence it is desirable to examine the standardization method, how it operates as a control, and to compare it with the legislative method, and the method of commission control.

The Consensus Principle

It is a commonplace that law, to be effective, must either be based upon thoroughly established custom, as was the common law, or it must be based upon a common understanding and a common purpose of the great majority of those concerned. Effective law is but one type, though an important one, of a real consensus, or at least of a real acquiescence, which means a common understanding, common purpose, and common consent.

Industrial customs and trade practices, or at least the more important of them, are, in a very real sense, industrial "law" no less than are statutes and the common law. Often more potent than much of the legislation on the statute books, they constitute a powerful system of controls which become generalized "law."

Most of these controls have come about by more or less unconscious evolutionary processes, but more recently they are being brought into existence in innumerable instances by deliberately planned, cooperative effort. As typical of these conscious, cooperative "law-making" processes there may be mentioned:

The numerous codes of ethics that have been adopted by commercial, industrial, and professional associations. While these have fallen far short of enthusiastic predictions made for them a few years ago, chiefly because they have not been sufficiently specific to serve as criteria in adjusting individual cases, they have attained to some importance.

Principles and working rules governing relations between employers and

employees, developed by such means as "impartial chairmen," direct negotiations between employers, and various types of labor organizations.

The voluntary rules developed by business groups under the trade practices conferences of the Federal Trade Commission.

Much of the work of trade associations.

Rules and machinery for the arbitration of commercial disputes. This method is in wide use as a substitute for litigation.

The standardization movement.

Most of these are based essentially, though with many variations, upon the simple process of the various parties at interest facing each other, and the common problems, across the council table, developing the facts, and sticking to the problem until agreement is reached upon the principles and the lines of action to be followed.

Standardization

Standardization is the establishing by authority, custom, or general consent, of a rule or model to be followed. In its broadest sense, it applies not only to such matters as weights and measures and material objects, but it permeates most fields of human activity. Folk-ways, taboos, moral codes, ceremonies, educational procedures, social and business customs, industrial practices, even language, are all forms of standardization. The main use of the term standardization is, however, in connection with technology, industry, and business, their products and processes.

Every industrial plant is carrying on standardization of its own products and processes, and its competitive success depends largely upon how well it has studied and solved these problems. Standardization within the plant has been the essential factor in the development of mass production—which is the most important contribution which this country has made to the development of industry.

Some of the more important phases of the movement have to do with dimensional standardization to secure interchangeability; concentration on the optimum number of types, sizes, and grades of products; specifications as a basis of purchase; methods of making acceptance tests for materials and apparatus; safety codes for the protection of workmen; building codes; traffic standards; nomenclature, definitions of terms commonly used in specifications and contracts.

All of these are matters which are involved in the relations between buyer and seller, and between competitors, and hence frequently become subjects of litigation in the courts, and of adjustment through other arms of government, particularly commissions and administrative offices. The purpose is not so much to settle controversies as to simplify and clarify matters so that controversies shall not arise.

For example, loose phrases in describing products, such as, "all materials shall be of best commercial quality," and "good workmanship shall be required throughout," which are even yet frequently used in contracts, are but invitations to the courts. In a wide range of products, such loose phrases are

giving place to definite, clear-cut specifications, which may be interpreted in the acceptance or rejection of material without danger of misunderstanding by any competent engineer or testing laboratory.

The purpose is to set forth so clearly the technique by which acceptance tests are to be made that any competent inspector can determine readily and definitely whether the material comes up to the contract, or guarantee, or not.

Often in commercial practice things which at first seem extremely simple turn out to be not so simple. What could seem simpler than to decide whether a piece of shafting is 2 inches in diameter? Yet, if nothing more is specified, a buyer may attempt to reject the material, claiming it inaccurate, no matter how accurate it may be, since it is impossible to make a shaft exactly 2 inches in diameter on account of unavoidable inaccuracies of workmanship. On the other hand, the seller may attempt to supply material so inaccurate as to be unusable, asserting that it is "commercially accurate." The solution consists in agreeing upon just how many thousandths of an inch departure from the ideal size shall be allowed for unavoidable inaccuracies of workmanship under normal conditions of commercial production. (The amount thus allowed is technically known as the "tolerance.")

Standards as Definitions

Another important line of activity which tends to reduce the work of the courts is in connection with definitions of technical terms used in specifications and contracts and in general industrial transactions. To realize the importance of this, one has but to recall that a large part of the civil cases with which courts deal hinges upon the exact meaning of words and phrases.

As a matter of fact, a large part, perhaps the greater part of standardization, is essentially agreement on definitions. When we agree on specifications for cement, we are really agreeing on what we mean by cement, so that we may telegraph, "Send one thousand barrels of cement according to the specifications," with the full assurance that there will be no misunderstanding of the requirements.

The same is true of methods of test, of grades and grading rules, and of methods of rating machinery and apparatus. It took a vast amount of technical study and many years of negotiations before a "10 horse-power motor" had the same meaning when used by competing manufacturers.

All buying and selling in which goods do not come under the actual eye of the buyer must necessarily be based upon some sort of standard. Most such standards are unwritten, simple, and crude, often being no more than a two-party understanding such as, "Like the one I bought of you last time." At the other extreme, all of the great basic commodity markets are dependent upon standards which are, in most cases, well worked out, are nationally accepted and used, and may even be subject to legal definition. In the absence of such standards, the buyer would himself have to judge the wheat, corn, cotton, or copper with his own eyes. A safety standard defines just what hazards shall be covered by the safety features of a machine, or by safe practices in an operation. In each case a standard enables buyer and seller, or

the parties to any other undertaking with which the standard deals, to speak the same language.

It is readily seen that all these features of the standardization movement partake of the nature of effective human law in its generic sense, that is, of principles of conduct, based upon a sufficiently broad consent or acquiescence of the groups concerned to assure general compliance with them.

Standardization Methods and Machinery

Most standards have come about through a more or less unconscious evolutionary process. Nearly all standards were developed in this way until within the last hundred years.

The conscious process of standardization in industry was first applied to engineering matters, but has been extended to foods and other agricultural products, in fact to innumerable products of farm, forest, mine, and sea. It helps to channel these materials through the many stages of manufacture. It has been concerned predominantly with producer goods.

There is an interesting analogy between this earlier growth of the standardization movement, largely unconscious, and the development of the fundamental principles of Anglo-Saxon law through the common-law process, which was unplanned and largely unconscious.

The standardization movement has been slowly systematizing its machinery and standardizing its own methods. In the past most companies have handled these matters in what may be termed an unconscious way, implicitly as part of other activities, following the lead of other companies, etc., without clear-cut analysis or organization for the problem.

Group Standards

The great growth of company standardization and mass production during the last half of the nineteenth century gave rise to group standardization which, with a few notable exceptions, has been a development of the present century. There are literally thousands of such group standards, most of which have been developed by technical societies and trade associations.

The present extensive use of electric motors and lamps has been made possible by collective standardization of such fundamentals as voltages and frequencies, and of such details as the interchangeability of lamp bases and sockets.

Probably the most important of all group standards is that of the standard gage and the system of interchangeable brakes and couplings, which has made possible interchange of rolling stock between railroads. Such interchange is necessary to our national railroad transportation system, upon which our whole economic and industrial structure rests.

National Standards

Just as standardization by individual companies led to standardization by groups, so group standardization has led to national or inter-group standardization among industries as a whole. In this, technical societies and trade

associations play the same role as do the individual companies in group standardization.

The methods used in formulating group, or association standards are very simple, being essentially committee methods. Customarily a standard is issued only when supported by a majority so substantial as to approach unanimity—almost never on a mere majority vote as so frequently happens in legislatures. Generally, final action is by the governing board of the association, but not infrequently it is by vote of the entire membership. Most of the more experienced associations have safeguarded their procedure to assure the most thorough consideration of the proposed standard before its promulgation.

Necessarily, national standardization requires the correlation of the work of the interested groups through a national clearing house agency. At the beginning of the present war, there was such a national body in each of twenty-six countries, including all of those countries which are highly developed industrially. All but one of these have been organized during or since the World War.

Our own national body, the American Standards Association, was organized in 1918. It is a federation of 73 national organizations, composed of seven departments and three other major agencies of the Federal Government; thirteen engineering and professional societies; and fifty national trade associations, including most of the heavy industries that are active in standardization work.

Developing a Consensus

The chief function of the Association is to provide the systematic machinery through which all the groups concerned with any particular standard participate in its development.

As an example of the standardization method of getting a national consensus let us choose a specialized but relatively simple industrial problem, the protection of workmen in the use of grinding-wheels. What are reasonable provisions for safety?

The work of formulating a safety code on the subject was carried out by a joint committee made up of representatives of all interested groups; the manufacturers through their national trade associations; state commissions having regulatory authority over safety matters in the industries, or charged with the administration of accident compensation, through their national association; employing groups which are users of grinding-wheels through their trade associations; casualty insurance companies through their two national organizations; the workmen whom the code is designed to protect, the representation being arranged through the United States Department of Labor upon nomination by the craft organizations concerned; national engineering societies; technical bureaus of the Federal Government; and independent specialists.

In all, seventeen national organizations are represented on the joint committee, which has thirty members. After two years of painstaking work, unanimous agreement upon a complete code was reached. This was not accom-

plished, however, without encountering some serious difficulties and differences of opinion. Through patient and conscientious effort a solution of all these problems was found.

The code covers the general safety requirements to be met in the construction, care, and use of grinding-wheels. Its authoritativeness is recognized by the industries concerned with their manufacture and use; all state regulatory bodies that have rules on the subject have adopted the code as their own regulations; and casualty insurance companies use it in recommendations to their insured. It has, in fact, become "the Bible" of the industry.

The code is kept up-to-date by revisions as new developments occur.

The backbone of the regulations of the various state governments for the protection of workmen consists of fifty such safety codes. Each code has been developed by the same general process and with the same care through systematic cooperation of all interested groups. After substantial unanimity is reached and registered by the action of the joint committee responsible for any particular code, the code is formally certified as the "American Standard Safety Code" for grinding-wheels, or for punch presses, as the case may be. This is done by the central organization which serves as a clearing house or means of systematic cooperation in this national industrial standardization movement—the American Standards Association.

A safety code has been chosen as an illustration, not only because of its more direct legal implications, but because of the diversity of the interested groups.

Work on other types of standards is carried out by the same general method. The groups concerned with commercial standards such as specifications, grades, and dimensional standards, usually come under four categories—producers, consumers, distributors, and independent experts. The number of groups interested in any particular project is surprisingly large, usually from ten to twenty in number. For example, twenty national organizations are participating through accredited representatives on a committee developing a series of standards for bolts, nuts, and rivets; thirty-two are on a committee on pipe flanges and fittings, and thirty-three on a committee on specifications for galvanizing. Even in so specialized a subject as railroad ties, twelve national organizations participated.

The Human Element

In standardization work the human element is far more important than is generally realized. In setting up standards, the human difficulties are usually much more serious than are the technical ones.

On the other hand, one of the chief functions of standards is to remove conditions which lead to controversies. As has been indicated, the lack of adequate standards is a prolific cause of controversy—parts that do not fit, supplies and materials that prove unsuitable because they have not been properly specified, goods that do not live up to sales representations. Such transition-point difficulties often result in feelings of resentment or of frustration on the part of the personnel involved, and thus give rise to con-

troversies—often deep-seated ones. Indeed a goodly proportion of present-day industrial standardization, such as that carried on by the national standardizing bodies, is undertaken in the first instance to remove controversies. These controversies are usually resolved, or at least greatly mitigated, by the introduction of standards which solve the mechanics of the difficulty.

Most cooperative work on standards is undertaken before controversies reach an acute stage. This, however, is not always the case. An example will illustrate the spirit in which such situations are approached.

Some years ago, the gas industry proposed to the American Standards Association that there should be national specifications for cast iron pipe. When the manufacturers were approached they said that it would be useless to talk with the engineers of consumer companies who were impracticable theorists. The engineers in turn said that it was hopeless to try to cooperate with the manufacturers who had been working off inferior pipe on them for a dozen years and whose willingness to live up to specifications they doubted. It was a year before it seemed safe to invite them to sit down in the same room to talk things over. After much talk they agreed to develop new specifications cooperatively. A wise and experienced engineer agreed to take the chairmanship of the technical committee, but only upon three conditions:

1. They must agree upon what they did agree upon and what they did not agree upon. That is, they must first agree upon the exact point at which the road began to fork. This was done, and agreement was reached upon what the moot questions were, one of which was the accuracy of a certain formula.

2. They must agree upon why they disagreed upon these moot questions. After long discussion they decided that there were insufficient known facts to give the answer, and hence one man's opinion was as good as another's.

3. They must decide upon what they were going to do about it. The final result was that the manufacturers raised some $70,000, which was expended in large part under the general direction of the engineers, and the necessary facts were obtained. With the facts at hand, the controversies disappeared.

The Three Fundamentals

This also illustrates three principles that are followed by the American Standards Association in order that a consensus may be established in the case of each standard. First, every group substantially concerned with a standard has an inherent right to participate in deciding what the provisions of the standard shall be, so that the standard shall represent a true national consensus.

Second, the questions are broken down into parts small enough so that each part can be handled by a committee made up of representatives of the groups concerned. Such committees are like a legislature, but organized along industrial instead of geographic lines.

Third, decisions are not made by simple majority vote, but every effort is made to thresh matters out so thoroughly that a decision is reached which is unanimous or nearly so.

An idea of the extent to which the national stage of the movement has

developed is given by the fact that over 500 national organizations, industrial, technical, and governmental, are cooperating under the auspices of the American Standards Association on some 600 projects, 425 of which have been completed and issued as approved standards. Three thousand men and women are serving on its committees. Only a very small part of the possible field has, however, yet been touched.

Limitations of the Standardization Method

The standardization method has its limitations and difficulties, most of which, as would be expected, are very similar to the difficulties and breakdowns encountered by other types of human agencies, governmental or voluntary, legislature or court, church or lodge.

The interested groups are often very unequal in strength and influence. Also they may be unorganized or very loosely organized, as is not infrequently the case among consumers as compared with producers, or small retailers as compared with manufacturers, a condition which often constitutes a serious handicap in standardization work.

There is much jockeying for immediate commercial advantage. There are endless jealousies and bickerings within and between organizations, and struggles over the prestige and vested rights of organizations—the nearest equivalent of party politics.

Most Americans do not understand the meaning of representation and its responsibilities—a source of serious weakness in nearly all forms of voluntary organization as well as in our government. (This is probably due to the fact that we are accustomed to speak of our government as being representative, while it is not representational in the sense that a parliamentary government is representational.) A closely related fact is that it not infrequently happens that men agree at the council table to an undertaking, with intentions of carrying it out, and then later fail to do so. This is one of the most frequent causes of breakdowns in undertakings under the cooperative method.

Then there is the problem of the "recalcitrant minority" (which in some cases is strongly organized and powerful) that refuses to cooperate unless it can have its own way completely. Frequently, in the opinion of the majority, such a group is not intelligent enough to know what its job is, and what in the long run will be most advantageous to it. In standardization work this difficulty is one which is much more apt to prevent the launching of a project than to wreck one after it is started, although instances of the latter do occur from time to time.

Of course, these and other difficulties are inherent in any important movement.

What Should Not Be Standardized

There is no value in standardizing merely for the sake of standardizing, in uniformity for the sake of uniformity. To do so takes variety and spice from life.

Standards should be set up only when doing so may be expected to result

in important economies; to simplify and clarify operations; or to safeguard persons or property.

It is idle to attempt to standardize style features.

It is not the function of a standard to prevent the marketing of any product, no matter how inexpensive, but merely to enable the buyer to know what he is getting.

Most business men think that the use of standards for commercial and technical purposes should be voluntary, and that they should be made mandatory under legal authority only when such a course is necessary as a protection to persons or property or to prevent fraud.

Importance in National Defense

The defense program brings the whole subject of standards into sharp focus. A manufacturer who takes a contract for a product which differs from his regular line of production is faced with the necessity of making many changes in the equipment and operation of his plant. His problems are much like those of an automobile manufacturer in re-tooling for a new model. These problems are basically problems of standardization.

Every government order carries with it the specifications or standards that define the gun, tank, blanket, or truck that the manufacturer has to make, or the materials that he has to supply. A single government order may extend to hundreds of companies—manufacturers of parts or suppliers of materials. Many of the companies will not have had experience with these particular products. Each of them in turn must control all his operations so that the completed product will comply with the standards originally laid down as a part of the order. Hence every one of these manufacturers must have a thorough understanding of standards—how to work to them in shop, processing plant, and assembly line.

The use of standards in the purchasing of supplies by federal, state, and city governments is closely related to the defense program and it presents a major opportunity for economy, principally to the public agencies, but also to a considerable degree to the business suppliers. The same is true of institutional purchasing generally. The Federal Government, a few states, and some cities have made outstanding progress in this field with resulting large savings. It has been estimated that the various bureaus and agencies of the Federal Government have in all some 7,000 specifications for the materials and supplies which they purchase. This covers both civil and military needs.

Partly as a result of the work of the Defense Commission, and partly as a result of criticisms by industry of troublesome differences in specifications used by the different bureaus and departments, the Government has plans under way for bringing all government specifications into closer accord, as has already been done in the case of some 1,300 specifications which have been unified under the authority of the Federal Specifications Executive Committee. This Federal Specifications work is attached to the Procurement Division of the Treasury Department. To help bring the work into closer

accord with industrial practice, the Treasury Department has recently affiliated with the American Standards Association as a Member-Body.

The integration of the entire process into a smooth flow like a great river system is an enormous undertaking. Shortcomings in the government standards or in the manufacturers working to them—too many kinds of products—obsolete requirements—unnecessarily close fits—faults in workmanship or materials—all result in bottlenecks which cut down the flow of the goods. A great many of these bottlenecks are due to a lack of adequate national standards acceptable to government and industry alike.

Summary

1. It is a commonplace that standardization has been an essential factor in the great increase in the real incomes of the populations of industrial countries since the latter part of the nineteenth century. This is because standards underlie all mass production methods, and because they facilitate the integrating processes necessary to large scale production and distribution.

2. Most of the criticisms that have been directed against standardization have been based upon the misconception that standardization means to stand still. To an industrialist a sound standard represents the best way of doing a thing—at the moment. If tomorrow he finds a better way, he will codify it in a new standard. Sound standardization is dynamic, not static. It means not to stand still, but to move forward together. By facilitating the flow of products through industry and commerce, standards help to maintain what an engineer would call *dynamic stability* in industrial processes—just as a motor car in motion or an airplane in flight will respond with nicety to the slightest touch on the controls, and will right itself instantly following any slight disturbance—such as a bump in the roadway or a gust of wind—provided the machine has dynamic stability. The danger of stagnation lies, not in the use of standards, but in taking a fixed mental attitude, instead of always keeping the mind receptive to new ideas.

3. In standardization, business has available a simple method of avoiding a great deal of governmental regulation, by solving many types of problems which give rise to it step-by-step, and doing so as they arise—instead of waiting until they pyramid into unmanageable form, resulting in legislation.

4. To accomplish this, industry will have to adopt the policy of taking the initiative in constructive action; the present trend cannot be changed by inaction. None of the principal organized business groups of a general character has adopted such a course as a major policy.

5. It has often been suggested that in standardization work an ideal relationship between industry and government has been developed, namely, that the government departments participate in an undertaking on precisely the same basis as that of any other organized technical, industrial, or consumer group. This means that they participate in proportion to their direct concern with the problem in hand, and to the extent that their technical resources enable them to contribute to the solution, rather than by assuming the direction of the whole undertaking.

6. The lack of a sufficient number of sound national standards is one of the main causes of the growth of trade barriers.

7. The problem of standards for consumer goods is a major one from the point of view of public relations of business.

8. A system of well articulated standards is basic to the defense program. It is equally important in peace time and in times of emergency. While the situation in regard to standards is decidedly better than it was in 1917, there is urgent need for far more coordination, both within industry, and as between industry and government.

CHAPTER XI

FACTORY COSTS FOR THE ENGINEER

Cost accounting is outside the scope of the production engineer. Cost of production, however, is very much his responsibility, whereas the reduction of this cost is one of his most important tasks. It is logical, therefore, to consider some of the elements that enter into these factory costs of production, and to give some thought to the procedure used in compiling the figures that are supposed to represent them, to some degree at least.

Many different methods are used to establish figures that are supposed to represent the cost of production. The costs of the direct materials and of the direct labor that enter into the production of any commodity are readily compiled from the requisitions for the materials and the workmen's time cards or records. The major problem lies in the attempt at an equitable distribution of the many items of indirect expenses. These are generally distributed arbitrarily as "overhead" charges or as a "burden" on the product, or on parts of the product. This is a necessary evil because the attempt to trace each supplementary charge to its original source involves a mass of detail accounting that would cost much more to carry through than the information would be worth. Hence any practicable method which we can afford to use must be arbitrary to a large extent. Nevertheless it should be possible to devise some method that would give a closer approximation to the true costs of factory production than those ordinarily used.

Cost-accounting procedure for this purpose has, in the past, been set up by the financial department, which attempts to obtain, in as simple a manner as possible, the information which it needs to explain all expenditures. There can be no quarrel over such aims or about the procedure; the point is that figures which may be adequate for the uses of the financial department may be absolutely worthless to guide the production engineer in his efforts to reduce costs or to serve as a measure of his success in achieving economies. In any attempt to obtain truer approximations for the use of the engineer, those needed here may give over-all totals not sufficiently accurate for financial accounting purposes. This is of little importance. It may be necessary to keep two sets of accounts; one for the engineer and the other for the accountant.

With the increasing use of automatic tabulating and other business machines, the cost of such double accounts should not be beyond reason.

Common Methods of Distributing the Burden

Among the many methods commonly used for distributing the indirect expenses so that a measure of the detailed factory cost of production may be had, we have the following:

(*a*) As a direct percentage of the amount of wages paid to the direct producers. This might apply best to the "technique" industries where the skill of the workman is one of the most important factors. Costs so determined, however, would be of little or no assistance to the engineer who was trying to reduce the factory costs of production.

(*b*) As a direct percentage of the cost of the direct materials. This might be adequate for the financial department of a "tonnage" industry where the volume and cost of raw materials were the important factors. Such values, however, would not be of any value to the process engineer in his attempts to reduce costs.

(*c*) As a direct hourly charge added to the wage of the direct producer. This is known as "man-hour" burden. This might apply in some degree to those workmen who were operating expensive production equipment.

(*d*) As a direct tonnage charge against the weight of the materials processed. This method is often used in foundries and in the heat-treatment departments of metal working plants.

(*e*) As a departmental burden to cover all the indirect expenses of each different department, distributed either as a percentage of the wages paid to direct producers or as a man-hour burden. In addition, some of the general indirect expenses of the plant must be added to the specific departmental expenses. This plan is a slight refinement of methods (*a*) or (*c*).

(*f*) As a "machine-hour" rate, where the indirect expenses are applied to each type of production equipment, as an hourly charge, so that all these expenses will be absorbed by the machine-hour charges. These expenses must be distributed on the basis of the cost of the equipment, or the amount of power that is required, or on the basis of some other analysis that may have been made. Such costs also are too far from the true costs of production to be of any particular value to the engineer.

For the financial purposes of cost accounting, if the total indirect expenses can be controlled, and the totals can be accounted for, even though some adjustment must be made at the end of each accounting period to obtain a correct balance, their exact distribution is not im-

portant. Any other distribution we may make will be nothing more than another approximation.

For the purposes of the production engineer, it is most important that the distribution of these indirect expenses should represent the closest approximation it is possible to obtain, because an important part of his work is to search out and correct conditions that result in too great indirect expenses. It is of little importance to him whether the totals of the estimated or approximated indirect expenses agree with the actual totals or not. If he can reduce the actual totals of these expenses, then the approximations will have proved their value.

Factors of the Factory Cost of Production

The factors of the factory cost of production may be divided into three general groups: (*a*) cost of direct labor, (*b*) cost of direct materials, and (*c*) indirect expenses.

As noted before, the equitable distribution of the indirect expenses is the major problem. This whole subject is highly controversial. No matter what method is used, it will be open to legitimate criticism.

The engineer is trained, or should be trained, to seek out cause and effect. Not until the causes are known and identified can the effects be altered consistently in the desired direction. Hence for purposes of cost reduction, as far as it is affected by the reduction of the indirect expenses, and for purposes of evaluating the effectiveness of the engineers' efforts to this end, these indirect expenses must be identified and distributed as far as possible according to their causes. This may be done by a process of elimination. For example, if some factor or element of the production could be eliminated, what indirect expenses would be eliminated also? Any indirect expense which would thus be eliminated would obviously be caused by the existence or presence of the eliminated factor.

But before we consider the causes and effects of the indirect expenses and decide upon some better method for their distribution, we must first study the nature of these charges.

Indirect Factory Expenses

The indirect factory expenses may be grouped into three general classes: (*a*) fixed charges, (*b*) general operating expenses, and (*c*) specific operating expenses.

Fixed Charges. The fixed charges include all those expenses that must be met whether the plant operates or not. These include taxes, insurance, interest on loans and mortgages, general maintenance of buildings and equipment, etc. Most of these expenses are beyond the

control of the production engineer, hence the method of their distribution is of little interest to him. They may be included in, or omitted from, his factory cost accounting as may be most convenient; it will make little difference to him as regards the value or utility of the figures which are used to represent the costs with which he is most concerned.

General Operating Expenses. The general operating expenses include all those which are incurred for the general operation of the plant, or of any individual department, which cannot be charged directly to any specific part of the product, or to any specific process, or to any specific part of the direct labor or the direct material. Such charges must be distributed on some average or percentage basis over the product of the plant as a whole, or over the entire product of a single department. These expenses include the costs of the following items: supervision, light, heat, maintenance of sanitary facilities, safety precautions, employment department, payroll department, time and cost department, engineering department, purchasing department, records, shop clerks, supplies of many kinds, handling and storage of materials, general maintenance of equipment, etc. Such charges may be called "general expense charges."

Specific Operating Expenses. The specific operating expenses include all those which are incurred by the operation of some specific equipment or process, or for the production of some specific part of the product. These expenses have a direct relation to the quantity or variety of the production. They include the costs of the following items: power, special manufacturing equipment, expendible tools, lubricants and cutting fluids, spoiled work and correction of mistakes in the production, quality control, production control, production design, changes and corrections in the design, packing and shipping, etc. These expenses can be charged to specific types of operations or processes, types of products, and specific component parts of the product. Such charges may be called "specific expense charges."

Distribution of Burden

If we desire to have a reasonably close approximation to the actual cause and effect of the many indirect factory expenses, there are five general causes of these expenses. In all cases, some will be general expense charges while others will be specific expense charges. These five causes are as follows: (*a*) direct labor, (*b*) direct materials, (*c*) general productive equipment and machines, (*d*) product, and (*e*) plant.

As noted before, a perfect distribution of all indirect expenses is out

of the question. Yet we can, by a process of elimination, determine the place where a particular item of expense belongs. If when all five causes are eliminated, the expense remains, then it belongs to the general management or operation of the organization and can be applied as a percentage on all the finished product of the plant.

To obtain a definite figure to use as a burden, we must first separate these expenses into the proper classes and then decide how best they can be distributed. In effect, this will set up five different burdens, all of which we must add to the direct cost of the product to obtain the actual factory cost of any item.

Direct Labor Burden

Among the items of indirect expense that would be eliminated if we had a plant that could operate without any workmen engaged in the actual tasks of production are the following:

(*a*) Salaries or wages paid to foremen, supervisors, tool setters, timekeepers, shop clerks, etc., who direct, train, and record the activities of the working force.

(*b*) The cost of lighting, heating, and ventilating the plant. Some of these charges may belong to other factors, but the larger part of them is incurred for the comfort and the protection of the health of the working force. As all these charges must be carried eventually by the product, they can be carried here if it is not convenient to break them down in detail. They can be separated by departments, if desired, on the basis of some survey or analysis. If the cost of light is included in the charges for electrical power, charges which apply mainly to the motive power for the productive equipment, the amount to be deducted for light may be estimated on the basis of a survey, and applied by departments.

(*c*) The cost of maintaining all sanitary services. This may or may not include the cost of janitor service such as sweeping, window cleaning, depending upon the general shop organization and the time records which are available. If these costs are grouped with the general plant maintenance charges, they can remain there, and be applied with those charges, it makes little difference in the actual figure obtained.

(*d*) The cost of all personnel activities, including the employment department, the payroll department, and all other personnel charges including the costs of operating a cafeteria. If the costs of the employment department are to be broken down into departmental charges, the rate of labor turnover in the different departments should be taken into account when these charges are distributed.

(*e*) The cost of all educational activities such as foreman training

courses, apprentice training, and all other special training courses. These charges belong with the general labor burden.

(*f*) The cost of accident, liability, and group life insurance, etc. These charges go into the general labor burden unless there are certain departments with greater hazards than normal. In those cases where the insurance premiums are greater than normal because of these conditions, the extra cost should be added to the departmental labor burden. Increased safety precautions may decrease these costs.

(*g*) The cost of first aid stations, and all other medical attention and services furnished to the personnel. These charges should be added to the general labor burden.

Some of these charges, as noted, can be segregated by departments. This should be done whenever it is possible to do so without an excessive amount of bookkeeping. Other charges are of a general character and must be distributed more or less uniformly over the entire working force. The total of these charges over a given accounting period can be used to determine the direct labor burdens for the succeeding period. These may be imposed as a percentage of the wages paid to the force working directly on production, or they may be imposed as an hourly charge or man-hour rate on each operator. In either case, with a continuing operation of the plant, if each succeeding accounting period shows a reduction in the indirect charges, it is good evidence that effective use is being made of this information.

It would be worth while to establish departmental labor burdens or man-hour rates, and to try to arouse competition between the different departments to see which department can reduce these charges the most, and also to see which can attain and maintain the lowest amounts.

Direct Material Burden

It is a practice in many plants, particularly in those shops which make many custom-made products, to apply a "mark-up" or percentage to the actual cost of the materials to cover the cost of handling, storage, interest on investment in materials, and of making the materials records. The variety of materials and the average length of time during which they are carried in stock is much greater in a jobbing shop than in a plant that manufactures definite specialties to meet a definite production schedule. In this last case, the shorter the time that elapses between the receipt of the material and its fabrication into the finished product, the less will be the amount of working capital that is tied up in the shop inventory, but whatever the circumstances may be, the position of any manufacturing plant, in regard to

the direct materials, is similar to that of a storekeeper or merchant who must carry a suitable stock of merchandise to meet the demands of his customers. This involves certain handling and carrying charges which must be absorbed by the selling price when the goods are sent to the customer. Similarly, the raw materials entering into the construction of any product must carry a mark-up or burden to cover the expenses incurred because of them. Some of these charges may be applied directly to specific items; others are general and must be distributed over the entire stock of materials. Among these indirect charges are the following:

(*a*) Wages paid to storekeepers, stock clerks, truck drivers, etc., for handling, recording, storing, and issuing the raw materials. These are general charges which must be distributed over all of the purchased materials.

(*b*) Most of the operating expenses of the purchasing department. These charges are also general in character, and must be applied as a definite percentage added to the purchase price of all materials.

(*c*) Rental charges established on the basis of the amount of floor space used by storerooms for these materials. The amount of these rental charges can be determined from the costs of carrying and maintaining the plant buildings, etc., exactly as though this space were rented to some other tenant.

(*d*) Cost of trucking and freight or other transportation charges on incoming materials. Many of these freight charges can be applied directly to the materials involved. Some of the plant trucking charges apply to the expense of shipping the finished products. Possibly these charges could be halved, one part charged against the materials and the other part charged against the shipping of the products.

(*e*) Interest on capital tied up in raw material stores. This can be applied directly to specific materials or types of materials. The average length of time that any given type of material is carried in stock, from initial receipt to assembly into finished product, should be determined. Cost reduction efforts to reduce this elapsed time can then be measured definitely by the change in this indirect expense item.

(*f*) Cost of obsolete material as a result of over-stocks when changes are made which eliminate the need of such material. This item should be credited with anything received on its re-sale either as scrap metal or returned material. All normal carrying and handling charges must be added to the purchase price of such material to obtain its factory cost.

(*g*) Cost of any material which spoils in storage. This includes any

general supplies as well as any materials such as rubber tubes, which may be used to make parts of the product.

(*h*) The materials burden should be credited with the price received for salvaged chips and any other scrap material sold.

(*i*) Cost of collecting, sorting, baling, and other handling charges incurred because of the handling of these chips and other scrap materials.

For each type of material, the mark-up is the sum of the general mark-up which is applied to all materials and the specific mark-up which applies to the particular case.

Machine-Hour Rate

Among the indirect charges which are incurred because of the existence of the machines in the plant are the following:

(*a*) Cost of power. This should be distributed among different types of equipment on the basis of the average amount of power consumed. A survey and measurement of the power consumption should be made to establish these values. Periodical checks of this character are in order, and are a responsibility of an electrical engineer who is attached to the staff of the plant engineer. The average production plant is wasteful of the electric current it pays for, often using large motors running at fractional capacities. Power surveys often show many ways in which this waste may be materially reduced.

(*b*) Interest on investment tied up in this equipment. This is based upon the inventory value of the individual machines.

(*c*) Depreciation and obsolescence. This is a definite amount for each specific piece of general purpose manufacturing equipment and is based upon the values which the accountant already uses for these charges.

(*d*) Rental charges on floor space required for machine, or work bench, and the working space required around it. As noted before, these rental charges are based upon some of the general plant charges.

(*e*) Cost of lubricants and cutting fluids. These should be established for the different types of equipment, taking into account the influence of working on different materials and of working at different cutting speeds and feeds. A budget for these supplies should be set up for each department on the basis of the general shop average, and each department should strive to keep within its budget.

(*f*) Cost of repairs. Records of these costs should be kept for each type and model of equipment, and the average repair charge can be established from these records. If these charges are higher than average for some types or conditions of materials, such as when the

machines are working on a harder steel, the extra cost is a burden on those parts of the product which use such materials.

(*g*) Cost of moving and installing the equipment. Records can be kept of these costs for different types of machines together with a record of the average length of time this equipment is used in one place. From this information, an average value per hour of use can be determined. The charges for moving equipment that is re-arranged for the making of a particular product should be charged to that product.

From all these, and similar indirect charges, a fixed hourly rate for each size and type of equipment can be established. The average number of hours per accounting period during which the equipment is actually working on production should be determined. The hourly rate should be based on the actual producing hours and not on the total working hours of the plant.

Product Burden

Some of the indirect expenses created by the existence of the product are of a general character, that is, these expenses should be distributed over the product as a whole. Others should be applied to one type of product or to a complete mechanism. Still others should be applied directly to the factory cost of an individual component part. Such burdens can be set up as a definite cost per unit of production. One advantage of having such individual product burdens is to make apparent the true economy of the simpler and sturdier designs as compared with the more intricate ones. Another advantage is that we would have a closer measure of the cost of changes made to facilitate manufacture, many of which might have been anticipated had we made a more nearly complete production design.

Among the indirect expenses for which the product itself is responsible are the following:

(*a*) Cost of production planning, scheduling, and control. This is a general expense and should be spread over the entire output of the plant.

(*b*) Cost of the production design, including the cost of keeping the component drawings up to date. This is a general expense for the particular type of product involved, and should be charged directly to that product. The cost of the original production design may be a deferred charge which must be absorbed by a fixed volume of production.

(*c*) Cost of tool design and tool making. These are specific expenses and should be charged to the particular component part for which these tools are made. Some decision must be made as to the number

of parts which will be used as a basis of the rate at which these charges will be absorbed. Any differences which may exist between the assumed number and the actual number of parts produced during the life or use of these tools are charged to a profit-and-loss account to offset part of other charges for changes in tools during production.

(*d*) Cost of expendible tools and maintenance of all tools, including tool-sharpening and the storage and issue of tools. These are handled as general charges, segregated by types of tools, and applied to the operations in the different departments which use these tools. The cost of many of the items here is small, but the total cost of all is appreciable. For a delicate tool which requires more attention than the average tool, all these charges which can be readily segregated should be charged directly to the particular component part on which this tool is used.

(*e*) Cost of the design, maintenance, and carrying charges of special machines. These should have their machine-hour rate established on the same basis as the standard machine tool equipment. The first cost, which includes all design costs, will be higher than for ordinary machinery, and the depreciation should be greater because a change in the design of the product may make such a special machine obsolete. Or again, instead of charging the first cost to capital expenditure and then applying depreciation charges, the cost can be handled as a deferred charge which must be absorbed during the production of a quantity of the product. In either case, such charges should then be applied as before against the cost of the product made on these machines.

(*f*) The cost of spoiled work. Charges for this should be applied to the specific component parts spoiled. If such spoiled work leads to the disassembly and re-assembly of the product, or any unit of it, these additional costs of assembly should be added to the cost of the spoiled parts.

(*g*) The cost of heat treating. These charges are often distributed on the basis of the weight of the parts so treated. If some parts require a special series of heat treatments and unusually close control, such additional costs should be segregated as far as possible and charged directly to the component parts involved.

(*h*) Cost of painting, plating, or other finishing operations. Some of these expenses may be determined for each individual part or product; others must be handled as totals and be distributed according to the number of parts, weight, or size.

(*i*) Cost of quality control. These expenses include the wages and salaries of the inspection staff, charges for operating the testing lab-

oratories, and cost of designing, making, and maintaining the inspection facilities. Most of these charges are general and should be distributed over the entire product. Some can be segregated as departmental charges. Others apply to a particular product or type of product. If some individual component parts require an exceptional amount of attention, the charges for such critical inspection should be segregated and charged to these specific component parts.

(*j*) The cost of packing and shipping the product. Some of these expenses are general and should be distributed over the entire product. Others are more specific and should be charged against the specific type of product involved.

General Plant Expenses

The general plant expenses can be separated into three general categories: first, the fixed charges; second, the cost of management; and third, the general plant charges which cannot be definitely assigned to any one of the other elements of direct labor, direct materials, machinery, or product. The cost of management must be distributed over the entire output of the plant. Most of the fixed charges and all the general plant charges are used to establish the rental rates to be applied to those burdens where such rates are called for. Among these indirect expenses are the following:

(*a*) Cost of general management including the expenses of the general manager's office and staff, cost accounting, research, standardization, process development, product development, and contributions to educational and welfare and trade associations. As noted before, these charges are distributed over the entire output of the plant.

(*b*) All fixed charges including taxes, property and business insurance, interest on loans and mortgages, general maintenance of buildings and grounds, depreciation of buildings, etc. These charges are a part of the total from which the rental rates are established.

(*c*) All general plant expenses not included elsewhere, including the cost of the plant engineer's office, operation and maintenance of plant facilities, etc. These charges are also a part of the total from which the rental rates are determined.

Compilation of Burden

As noted before, all the indirect expenses of the manufacturing plant must eventually be carried by the product which is manufactured and sold. No claim is made that the foregoing analysis is the best that can be made or that it is complete. The essential feature about the determination and distribution of the many indirect expenses, if they

are to be of value to the engineer, is that the procedure followed must give a reasonable approximation to cause and effect.

Under the foregoing or any similar plan, we can separate the indirect expenses into several categories, as follows:

(*a*) Direct labor burden, general and specific.

(*b*) Direct materials burden, general and specific.

(*c*) Machine-hour rate.

(*d*) Product burden, general and specific. This can be divided into a general or departmental burden on the component parts and a specific burden for each individual component part; also both general and specific burdens on each type of assembled or completed product.

(*e*) General plant expenses. Part of these are applied to rental charges for the space used by the equipment, and part to the general product burden.

The over-all cost of any specific item of finished product is then the sum of the following:

(*a*) The cost of direct labor plus the general labor burden plus the specific labor burden assigned to that product or the departmental labor burdens.

(*b*) The cost of direct materials plus the general materials burden plus any specific materials burdens which are involved.

(*c*) The cost of the use of the productive equipment which is the product of the number of hours this equipment is used and the machine-hour rate.

(*d*) The product burden which includes all product burdens which apply to the specific item of product.

Uses of Burdens

In addition to the engineers' uses of such a type of cost analysis, the information so obtained has other valuable applications. For one, it enables accurate budgets for the different departments and projects to be set up more intelligently. Not only this, but it also makes possible a more direct control of these budgets. In addition, the cooperative effort of the engineer and the accountant which is needed to set up and operate such cost accounts trains the engineer to be more cost-conscious in all his work.

Such detailed information can be assembled in many different ways. For one thing, the cost of mistakes can be brought closer home to the individual or group which is responsible for the mistake. For example, if a mistake or an oversight in making the production design results in expensive changes in the work of preparation or initial production, the cost of the necessary corrections should be charged to

the production design group. If such charges are included in their expenses, when a comparison is made between their budget for this project and their actual performance, this group will have to explain the reason for exceeding the budget. This acts to make the group more careful in the future to avoid repeating the same kind of mistake. In other words, it should make them realize their responsibilities more acutely. The same practice should be followed for any mistake made by any other group.

It is worth while to let all the personnel in the plant know the detailed burdens on the several elements of production, and to specify the character of the expense items that build up these burdens. If a general departmental labor burden is used; and this burden is, say, one hundred and fifty per cent, it is only natural for many of the workmen to feel that the "white-collar" group is getting all the cream while they must be content with skim milk. On the other hand, if they know that the "stuffed shirts" are only getting a small percentage of the total, and that most of it comes from the wages of the sweepers, oilers, service men, truck drivers, storeroom clerks, tool setters, and foremen, and the costs of lubricants, cutting coolants, insurance, taxes, new developments which must be made to keep the plant in business, paper towels, soaps, and other supplies—many of which they use themselves—as well as from the costs of mistakes which they themselves make from time to time—then the chances of securing their full cooperation in all efforts to reduce costs by the reduction of these indirect expenses and the reduction of waste will be greatly increased. Detailed amounts are much more convincing than general statements or averages since these are often difficult to explain.

The establishment of machine-hour rates for the different types and sizes of machine tools is of great assistance to the process engineer when he is planning the manufacture of a new product. If his choice of processes is based on the direct labor cost alone, the actual cost of operating this equipment may be so great that the choice of some other process with a higher cost for direct labor and a much lower machine-hour rate would be cheaper.

If the practice of using the different types of burdens became general in any industry, their trade association could add to its objectives that of establishing average values for several of these burdens. With averages established for such items as direct labor burden on different types of operations, materials burden, and machine-hour rates for the most common types of equipment used in their industry, any manufacturer could compare his values with these averages. If any of his values were greater than these averages, it would call to his attention

the probable existence of conditions in his plant which ought to be improved. If his values were less than these average ones, he would have reasonable assurance that the conditions in his plant which influenced them were probably satisfactory. He could then devote his attention to other conditions that might need improvement. As with many other problems, a standard of measure or comparison is a first essential to consistent improvement.

Summary

As a summary of the proposed methods of distributing the many types of indirect expenses to the product by a procedure which applies the burdens to the places where they originate, we will consider the many necessary activities outside of the direct production effort, and trace the path of their expenses to their application to the product itself.

First we have the general management and all the general policy-making and general administration of the organization. These activities cover all phases of the work of the plant and cannot be segregated in any significant manner. Hence we apply all expenses incurred here directly to the finished product as a whole. This work includes general research, cost accounting, and standardization. It may or may not include expenses of process development and product development, the action depending upon the organization and application of these activities. If they are devoted to a specific project, such as the improvement of a particular type of process or product, they may be applied to that factor. As they are moves to meet future possibilities, and may need to be financed by current income, although many of them may have no possible commercial future, most of them should be classed with the general administration expenses. On the other hand, if certain projects are undertaken to meet actual difficulties with the present product or current manufacturing practices, then the expenses incurred can be logically charged against the product or process responsible for them.

Next we have the design of the product, including the functional design, experimental model, production design, and the manufacturing models, if such are made. The expenses of this work can be charged to the specific type of product, or to the specific product, for which the design is made. These expenses, however, may be incurred in one accounting period although the production will start in a later accounting period. They may be handled as deferred charges and later applied to the product as it is made. Here some arbitrary quantity of product must be assumed over which to spread these costs. On

the other hand, if such design on some new product is always under way, a definite budget for that work can be set up and these charges absorbed in current expenses and distributed over the entire product of the plant.

Then we have all the expenses of the preparation for manufacture. For major projects, these are deferred charges and are distributed over the specific product involved, both as assembled product and specific component part burdens. A similar treatment applies to minor changes and corrections during production, and to other minor preparation projects. Most of these last expenses are deferred charges and are absorbed in a shorter time than those for a major project. It is good practice to amortize all deferred charges as quickly as possible.

Finally we have all the operating expenses of the factory itself, including fixed charges and plant maintenance. The indirect expenses here incurred reach the product by various paths. The fixed charges and many of the plant maintenance expenses are converted into rental charges and applied to the item that uses the space, then through it to the product. The materials burden is passed to the component parts made from them together with the cost of the direct materials, and thence reaches the product. The machine-hour rate is charged to that part of the product which uses the equipment. The man-hour burden is added to the wages paid for performing a definite operation on some part of the product. The costs of production planning, scheduling, supervision, and inspection are absorbed by the product burden. Thus eventually, all expenses, both direct and indirect, are applied to the factory cost of production of the commodities which are made there.

The totals of these costs over any given accounting period need not agree exactly with the accountants' records of actual expenditures. They should, however, be approximately the same. The financial cost accounts may be kept in a much simpler manner so that any differences between the actual and the estimated expenses can be readily adjusted. As noted before, if the engineer takes full advantage of the more detailed analysis, and is able actually to reduce or control costs, both direct and indirect, more effectively, then the financial cost accounts should show a direct reflection of these improved conditions.

CHAPTER XII

PROCESS DEVELOPMENT

Process development, which includes the creation and perfecting of entirely new processes, the improvement of existing processes, and the adaptation of an old process to a new use, is one of the most important of the supporting activities of production engineering. These process developments may be divided into two principal groups: the development or improvement of a type of process which will have many applications, and the improvement or adaptation of an old process to meet a specific need or purpose. The first group will be called "general process developments," the second, "specific process developments."

All the standard processes used today are the results of general process developments of earlier years. Most of the particular practices and processes used in a specific type of industry or in an individual manufacturing plant are heritages from our predecessors, and are the results of their specific process development. Therefore, to insure the industrial progress of the future, we, in turn, must contribute our part to these process developments.

Sources of Process Development

Process development may start from any one of many sources. Often it is an act of necessity. Some existing process proves to be inadequate for a particular job, and a better solution must be found. At other times, it is largely a matter of inspiration; yet those inspirations that materialize usually come after a long and continued study of a particular problem.

Among the many possible sources of process development are the following:

(*a*) From outside sources. A new or improved process may be developed in some outside plant and be called to our attention by an advertisement or by a representative of the organization which developed it. Under such circumstances, the only experimental work involved will be to prove the value of this process to our own work. Generally the burden of this proof is left with the organization which developed the process. Modifications may be necessary, either of the process or of the product, to use this process to the best advantage.

Again, new equipment may be ordered to perform certain manufac-

turing operations on parts of our product. The order calls for the equipment fully tooled to do the work and it is left with the machine tool maker to plan, design, and make all the necessary accessories. In this case, the machine tool manufacturer may need to carry through some minor process development to accomplish the assigned task. In fact, many machine tool builders today must develop and sell a process rather than merely sell machinery. Most of these outside process developments belong in the class of general process developments.

(*b*) Definite developments to meet specific needs. Often a definite process development project must be carried through in order that a new product may be made. Each project of this kind is a problem of its own. It is best to break down these projects into several stages, starting with as simple a preliminary survey and series of experiments as possible. If the results of the preliminary experiments show promise of success, further work along these lines is justified. If the experiments are successful and the laboratory technique has been established, then work on an experimental production process should be started. When this is finished, and the new process has proved itself to be adequate, then the actual production process and all the necessary equipment can be designed, constructed, and put into operation. It is a good plan to set up budgets and tentative schedules for each item or stage of the work.

For example, a company made insulated copper wire as one of its products. Originally the wire was covered with a paper tape which was wound around it before it was covered with braiding. The company came to the conclusion that if they could make a paper coating directly on the wire, it would be more effective in operation and less expensive. After some study of the problem, a laboratory set-up was made on which they conducted their first experiments, during which they determined the proper condition for the paper pulp, an adequate method of rolling or squeezing the pulp on the wire after it had been passed through the pulp, and a suitable method of drying. This first laboratory set-up handled a single strand of wire, and much of the equipment was controlled by manual operation. When the laboratory technique was established, an experimental production unit was designed and built which handled three or four strands of wire simultaneously. Further experiments were made with this equipment to determine the possible speeds of operation, methods of control, and the best conditions of drying. After these experiments were completed, with this information available, the actual production units were designed, built, and put into operation.

Most of these developments fall into the class of specific process

developments, although a few will develop later into general process developments.

(*c*) By-product of research. One of the many by-products of research is the uncovering of information that indicates the possibilities of a new process development. This may come, for example, from a fuller knowledge of the behavior of some material under special conditions. With this knowledge as a cue, simple experiments may be made apart from the research program to test these changes. If the results are encouraging, the succeeding development may be carried on in the usual way until the new process has grown into a commercial asset. Such developments may fall into the class of general or specific process development. Each is unique, and the essential thing is that some person be present who recognizes the import of the phenomenon.

(*d*) Developments from suggestions. Many specific process developments originate in suggestions received from any one of several sources. They may come from workmen, supervisors, engineers, salesmen, customers, or visitors. Sometimes a complaint from a customer has in it the germ of an idea which later leads to a new process development. Some suggestions may be discussed many times and may be turned down, only to appear later with more supporting data and to be accepted. From whatever source the idea may come, however, the procedure for its actual development should be the same as for all others; it should be first tested with a series of simple experiments, and discarded or followed further as the results of the experiment indicate.

Responsibility for Development

The responsibility for process development may be assigned in many different ways, but it should always be kept distinctly apart from routine production. If there is a process engineer who is normally assigned to routine production tasks, and who is also valuable for the prosecution of a definite process development project, he should be temporarily relieved of his routine production duties and assigned to the specific project.

One way of handling these projects is to assign one individual, or to organize a special group of process engineers, to carry out each definite project, selecting them from any part of the organization where they may be found. Whether or not the project is successful, the temporary grouping of men from different departments to work on a common task will be of value in improving the personal relations and the cooperation between them.

In some plants, there is a small permanent process development

group that organizes and directs all these activities. This group will be augmented by other men who are assigned temporarily to a definite project. The attack on these development problems has its own technique. It is of great advantage to have a permanent group available which has acquired it. Much time can thus be saved that would otherwise be lost, especially at the start, if men who are familiar with this type of work are used.

Ideas for process development which originate in a general research division may receive a preliminary try-out there, but they should be transferred to the plant process development group for their full development as a shop process.

Wherever there is an appreciable amount of process development, there should also be a manufacturing experimental department where the first experiments can be made and the laboratory technique established. When a separate department of this kind is not justified by the amount of this work, then these tasks, together with those of making experimental models and manufacturing models, can be added to the work of the emergency tool room.

General Process Developments

General process developments may be divided into three general classes: (*a*) invention of an entirely new process, (*b*) refinement of an existing process to make it more effective, and (*c*) adaptation and refinement of simpler and cheaper processes as substitutes for more expensive processes. As noted before, all the standard processes used today are the results of process developments made in the past. It is of interest and value to consider briefly some of these earlier process developments.

Examples of General Process Developments

(*a*) In the early nineteenth century, Eli Whitney invented the cotton gin to separate the seeds of cotton from the lint. This replaced the hand seeding of the cotton and greatly reduced the time and cost of this operation. The reduced cost of cotton lint increased its market. The success of this mechanical contrivance was an incentive to the invention of other mechanical devices for the spinning and weaving of fabrics. Incidentally, although one of these cotton gins did the work of many people, it did not reduce the amount of work for men to do, but rather led to more and wider opportunities for employment.

(*b*) A few years after the invention of the cotton gin, this same Eli Whitney invented the milling process to take the place of filing when many similar parts were to be made. This development was among

the first of a series of later ones made by other persons, developments which form the foundations on which rest our modern mass-production methods. Eli Whitney was also among the first to apply the principle of the sub-division of production effort into simple and elementary tasks.

(*c*) Fifty or sixty years later, the form-relieved milling cutter was invented. Until this time, all formed milling cutters were resharpened by regrinding the formed cutting edges—a slow and expensive operation which required much skill on the part of the tool sharpener. The form-relieved milling cutters are resharpened by a simple grinding operation on the cutting flutes.

One of the earliest and most common applications of this development was the use of these form-relieved cutters to mill out the tooth spaces of gears. Until that time, the great majority of metal gears used in industry were molded and cast—tooth forms and all. This practice limited the materials for these gears to cast iron, cast steel, brass, and bronze. With the use of the new cutting tools which were easily resharpened, forged steel and other materials were made available for the making of gears. In addition, the cut gears were more accurate than the cast-tooth gears of that day. This increased accuracy, in turn, made it possible to run the gears at faster speeds.

(*d*) Some time later, the sensitive drill press was invented. This invention consisted of mounting the drill spindle in a quill which was moved to and from the work by a rack on the quill and a pinion on the end of a shaft. The shaft was operated by a hand lever mounted on the other end. The driving pulley was mounted on the frame of the machine so that none of the pull of the driving belt was transmitted to the drill spindle. The drill spindle was driven by a key in the drive pulley which engaged a spline or long keyway in the drill spindle. This construction made it possible for the operator to feel the thrust of the drill against the work, a condition which reduced the breakage of small drills. It also resulted in an increase in the rate of production on this process.

(*e*) In 1908, F. W. Taylor presented a paper entitled, "The Art of Cutting Metals," before the American Society of Mechanical Engineers. Besides presenting considerable data on possible and economical speeds and feeds for the cutting of metals, it revealed the possibilities of using higher speeds and greater feeds with alloy-steel tools properly heat-treated. This led to the development of many other "high-speed" tool steels.

If these improved cutting tools were to render their full service, the machine tools themselves had to be made heavier and faster in opera-

tion. Thus the introduction of these improvements forced a revolutionary product development in machine tool design. Almost before the capacity of the machine tools had caught up with the capabilities of the high-speed tools, cemented-carbide and tungsten-carbide tool bits, and other synthetic high-speed cutting tool materials were developed so that the modern machine tool had to be made even heavier and faster in operation than before.

(*f*) As noted before, the process of rolling screw threads was first developed as a cheaper method of forming these threads than the existing practice of cutting them with threading dies. This substituted a cold working process for the more expensive cutting process. The first use of thread rolling was for threading cheap bolts made of hot-rolled steel. Later it was discovered that this process would produce extremely accurate threads when the blank was smooth, round, and accurate in size. Today this process is used to produce screw threads on parts of many different materials to all degrees of accuracy that are obtained by other methods, even to the threading of small taps made of tool steel.

(*g*) Die casting is another process that has been perfected in the not distant past. As noted before, its use is limited to metals with relatively low melting points. This process is the improvement and substitution of an inexpensive hot working process for many other expensive cutting processes. Frequently the part as it comes from the casting die is practically ready for assembly.

(*h*) The development of generating processes for the forming of gear teeth such as hobbing, shaping, and grinding as a substitute for the milling process is of comparatively recent origin. These new generating processes have been introduced that we may achieve greater accuracy of the product. The use of these processes has reduced the number of different kinds of cutting tools needed to produce a given variety of product. In addition, their use allows more latitude in the design of the gear-tooth forms so that the inherent properties of the tooth curves can be utilized to a much greater extent than before.

(*i*) The invention and further development of turret lathes, starting with the hand screw machine, introduced a series of tools, adjusted for successive operations, which were permanently mounted on an indexing turret. This was a substitute for single tools which had to be changed and adjusted in the tool post of the lathe to allow a series of operations to be performed. In addition, a series of adjustable stops for the carriage or ram of the machine were introduced so that after they were once adjusted for the first piece of work, additional duplicate parts could be rapidly machined. The hand screw machine was

soon followed by the invention of automatic screw machines which could go through the successive operations under mechanical control. Then one operator could attend to several machines. These were called screw machines because a large part of the product which was first made on them consisted of screws of many kinds.

Larger machines of the same general type, both hand-operated and automatic, soon followed for the production of larger parts. Some have a single work spindle with a series of tools mounted on a turret and on cross-slides. Most of these are known as turret lathes. Others were developed with multiple-work spindles which are indexed from one position to another to engage a group of cutting tools mounted at each working position. Thus from the original hand screw machine have been developed a great variety of hand, automatic, and semi-automatic screw machines, turret lathes, automatic lathes, and chucking machines.

(*j*) Other process developments were similar to the transformation of the lathe into many types of automatic screw machines. Most of these developments have consisted of making semi-automatic and full-automatic machines which do the work of hand-operated equipment of the same kind. Thus the use of multiple-spindle drill heads on hand-operated drill presses led to the development of automatic drilling machines with several multiple-spindle heads. These will drill all the holes in the component part in all directions at one operation. On other types of automatic machines, several different types of cutting processes may be working simultaneously on the same component part.

(*k*) A comparatively recent process development is the introduction of various types of multiple-station automatic machines where multiple-work spindles are indexed from one station to another. Each working station is equipped with a variety of cutting tools while one or more stations are kept open for loading and unloading the work from the machine. With these machines, a part, nearly or completely finished, is removed each time the work spindle is indexed.

(*l*) As mentioned before, the cold working coining process has been developed as a substitute for milling the faces of bosses and other small spots on many types of forged parts. The results of this process are an improvement of the product, including increased accuracy, a decided improvement in the condition of the material, and a lower cost of production.

(*m*) Welding is another process that has received much attention in the past few years. As a result of developments in this field, many plants are now making welded frames to take the place of castings and to obtain increased stiffness, a saving in weight, and lower costs

of production. Various types of welding are now used for many kinds of assembling, often as a substitute for riveting.

One interesting by-product of this welding development has been the introduction of flame-cutting. An irregular form is cut or burned out of a plate by the use of a welding torch which melts out a small space around the outline of the required form. This flame-cut form may or may not be finished by other methods, the choice depending upon its requirements. Much of this work is done at the steel mill, a practice which saves appreciable freight charges because of the absence of the surplus material. The parts of many welded frames are cut to form by this method.

(*n*) Flame-hardening is another recent process development which permits the hardening of specific surfaces on large and small parts, but it is still in the early stages of its development.

(*o*) Surface broaching is another new process that has been developed recently to take the place of milling. When large numbers of duplicate parts are required, this process is faster, more accurate, and generally cheaper than milling.

(*p*) The grinding of thread forms from the solid material is another new process development, forced largely by the demand and need for more accurate thread forms on various types of component parts, many of them parts for airplane engines.

(*q*) The development and use of many types of molded plastics is another new process that is still in its infancy. Some of the first uses of these materials and processes were in the manufacture of novelties of many kinds, covers for mechanisms, and other non-structural or non-operating parts of products. As the physical properties of these plastics are improved, greater use is being found for them on some of the operating and structural components.

No list such as this would be complete until it included all the processes now used in industry. As noted before, every one of them originally started as a process development project. Many started as specific projects, and later were found to have a much wider field of application.

Examples of Specific Process Development

There is no end to the number of specific process development projects which have already been carried through and of others which are now in progress. A few examples are enough to indicate the character of this work. If any appreciable improvement over existing conditions is to be made, the initial objective must be set so far ahead of present practice that radically different methods must be studied.

As a first example, we will consider briefly the development of the finishing process now used on automobile bodies. A few years ago, an automobile body spent at least a week in the paint shop. Here it received a priming coat and two or more coats of color and several coats of varnish, which all were rubbed after drying. A group was organized to study this problem and to develop an improved process, primarily because the amount of floor space required for the constantly increasing rate of production was so great that the situation was becoming acute.

After a few weeks of study, this group was called in to see the director of experimental work and asked to report progress to date and to say what they hoped to accomplish eventually. When they replied that they hoped to save a day or two, the director told them that such a result was hardly worth while. He asked them to reconsider the problem and find out how they could reduce the time required in the paint shop to a single day.

Such an objective could only be reached by radical changes since minor improvements would fall far short. After considerable study, experiments, and research, much of it in cooperation with other outside research organizations, the answer was finally found in an entirely new type of quick-drying paint.

The following examples of specific process developments are quoted from papers published by the American Management Association in their *Shop Methods Series* 2, entitled "Process Development." We quote from the paper by George S. Case.

Ideas for new processes are like seeds which are produced in millions but which are of value only when they are matured to such strength that they are able to germinate. They must be carefully nursed in the hot-house where they can be given careful individual attention and raised in the nursery of the process development until they have sufficient strength to be transplanted to the factory.

The gathering of these ideas is a problem. Suggestion boxes and other methods are of some value but usually ideas which have sufficient strength to attract attention will drift around until they come in contact with some foreman, engineer, or executive who can put them under the care of the laboratory. There they must be carefully tested for the weeds which will cause trouble, perhaps at some distant point, and must be germinated and grown until they have enough form and strength so that they can stand the transplanting to a further development which usually takes the form of small scale manufacturing. Before they can be finally adopted as standards they must be transplanted to the regular organization and grown until it is determined that they have the strength to stand the variable whims of the

personnel and it has been proven that they will produce fruit satisfactory to the consuming public.

Of the many ideas which will reach the laboratory, only a few will ever get through to be a standard. We must raise them under conditions which will save those of value and reject the weak and dangerous. A very limited check of manufacturing institutions seems to find very few which have separate development nurseries for the handling between the laboratory and the standard stages, and this period is a trying one for the growing idea.

I think it can be said that in the very early stages a process is best developed under the close supervision of its originators or someone who is thoroughly sold and enthusiastic about it. Later it should come under the control of some others who are not so prejudiced in its favor, and finally it must be put into practice under the conditions that actually exist in the plants where it is to be used.

Good judgment is necessary to determine the amount of money which may be expended in the development stages of a process. Every care must be used to prove that a process will be not only economical and satisfactory to the manufacturing unit but that it will produce a product which will be entirely satisfactory to customers over the period of its usefulness. In few other departments of a business is the use of good judgment and sympathetic patience as necessary as in development of a new process. There are few other places where more money can be wasted, and certainly none where more money can be made, and there is little chance for the use of experience or records as a direct guide. This necessitates the close supervision of process developments by someone who is high enough in authority to have influence in the manufacturing, the technical, the selling, and the financial end of the business. Such a man will naturally have but little of his personal time to give, so that it is necessary for him to assign to the particular project a man of sufficient technical knowledge and above all of a sympathetic and patient temperament who can absorb and reconcile all the points of view which will develop.

It is probably advisable to allow small sums for initial experiments to almost any person in an organization for preliminary work on an idea. Frequently the best way is to instruct the laboratories to make certain experiments for anyone who has what looks as if it might be a valuable idea. Sometimes the converse is necessary and the factory must be instructed to test out certain ideas developed in the laboratory.

After the idea has reached the point where it might be dignified by being called a process, the amount of money which it is worth while to spend upon it should be very definitely decided and some thoroughly competent person assigned to its development with authority to use the resources of the laboratory or the factory. Unless this is done thoroughly and carefully many good ideas are lost and much money wasted.

We think our best way to handle development work is to divide it into definite projects.

It is always a question how much money should be spent on the development of ideas. Many good ideas have been lost because experimental work

was done with cheap and temporary equipment. On the other hand, a great deal of expensive equipment has been thrown away because ideas did not work out in practice. The people responsible for the development of processes are often expected to work upon a very meager allowance which necessitates the use of equipment which is patched up out of old material or is hastily and cheaply made. On the other hand, we all know that the originators of good ideas will spend more money in development and research work than most industries can earn.

The different ways in which new processes are developed in the average organization is illustrated by our experience with new methods for the heat treating of cold headed bolts in such a way as to increase the strength by a third or more over previous practice. Principles were discovered in our laboratories which were new in the heat treating of very low carbon steels and results were obtained which were specifically declared impossible in many text books. A process was developed upon these principles by our engineers and metallurgists and was finally put on a small scale production basis in one of our plants, but under the close supervision of the metallurgist who had been delegated to have charge of the project.

When it was thought that the process was on a commercial basis we installed it in other plants where it worked with a fair degree of success, but we found that it required such close control that it was not entirely satisfactory. After we had been using this process for several years one of our plants found that the work could be done in a simpler and more economical way. Our technical men frowned upon the idea as being entirely impossible. For some months a limited quantity of bolts was handled in this way with excellent results until finally the technical men had to admit that there was merit in the idea and it was placed in the hands of the same metallurgist and still further developed in the laboratory. Eventually all of the first lot of equipment was taken out and the heat treating departments revamped to turn out practically all low carbon cold headed bolts with this latter method of heat treatment.

In this case one method was developed in the laboratory and sold with some difficulty to the manufacturing units. In the other it was developed by the manufacturing units and sold with difficulty to the technical men, but the development was in the hands of a competent man who was able by patient and steady effort to put it on a standard basis. The results were excellent in each case although the second method superseded the first so quickly that it was necessary to take quite a loss in the early obsolescence of the first equipment.

Other bolt manufacturers have been experimenting with both of these methods without any remarkable success, and I believe that the reason is that the very complete and careful control which was found necessary for the first method and carried over into the second is the main thing that is responsible for its successful operation.

It is difficult to keep any accurate record of savings and it is questionable whether it is worthwhile for anything except developments which require very

serious expenditure. The result of changes can usually be dug out of routine cost records if there is any question about their economy. We have always tried to dodge giving credit for processes to any individual or even to any certain department. I think it has been the experience of all of us that no worthwhile idea is developed without the assistance, great or small, of every department and a great many individuals. Frequently one man who has contributed a very small idea may think that that is the fundamental thing that has made the process successful and we all know of cases where a very small change has made the difference between success and failure. If an effort is made to give personal credit, the feelings of many individuals will be hurt. It should be understood that each man is working for the whole organization and that it is entitled to his best efforts. If the credit is officially given to some one particular individual or department there is apt to develop a spirit of jealousy among the others which will prevent their giving freely the help that is necessary.

The only way to prevent duplication of development work is to have each project in the hand of someone who can act as liaison between the laboratory and the factory and between the various departments in an effort to see that experimental work is not duplicated. Sometimes such duplication is not entirely without value as very small differences will be made in experimental work which may mean the difference between success and failure. I suppose the answer is that this is not duplication but sometimes it is hard to tell when it is and when it isn't.

In most manufacturing organizations process development seems to be handled jointly by the staff and line organization. Perhaps this is necessary since the ideas very frequently come from the manufacturing organization and the research work must be handled by the engineers in the laboratories.

It has been my experience that the greatest difficulty lies in the selling of the new process as developed by the engineers to the manufacturing end of the business. If it is forced upon them too strongly every trouble which develops is magnified and frequently a process is scrapped before it has had half a chance. On the other hand, if the manufacturing organization has the final responsibility of the development and it has to be sold to them as it goes along there is usually slow progress and a great deal of doing over of experimental work which has already been done, and of attempting to accomplish new results by old methods, before the new ones can be sold.

If an organization is large enough and there are process developments of sufficient importance, a separate organization could doubtless function most efficiently. Coordination with the selling, as well as the engineering and manufacturing departments, would be very important and the value of such a department would seem to depend very greatly upon its ability to work with the others in a sympathetic manner.

In our own organization where the development is handled jointly by the engineering and manufacturing organizations, the only coordination is through the Vice President of the company in charge of manufacturing, and I know

that every new development takes a tremendous amount of sympathetic and tactful but strong and continuous pressure upon his part.

In manufacturing constant changes in process are necessary as improvements in methods of handling, fabrication, and treatment are found. Such changes are frequently dangerous. I remember very well many years ago changing from bone to hardening compound for case hardening monkey wrenches. Bone was becoming very expensive and the synthetic hardening compounds had salesmen in my office every week. Finally we made what were apparently thorough tests and found that one of the compounds gave us a much superior tool with a decrease in cost of production. We checked the result with a manufacturer of roller bearings and several others who were using the compound, and finally changed over to it. About three months later we found every monkey wrench in our inventory rusted solid. The bearing manufacturers were grinding after hardening and therefore did not develop the trouble which apparently arose from some chemical which remained after the hardening and dipping.

A change of process nearly wrecked one of the tire companies some ten years ago. The tires showed excellent results when fresh, but after a few months in storage they all had to be scrapped. The thorough tests made by the tire companies today, both in laboratory destruction tests and continuous and expensive road tests, show that they take no chances of such an expensive happening.

At the Caterpillar Tractor Company the other day I was told that some part of the daily production is put into service and out to the customer just as rapidly as possible. It is a general practice to use the oldest part of an inventory, and it is generally good practice. I understand that they usually use the oldest part of their inventory, both in raw materials and finished product, but that they insist that some part of the daily production be put right through into the hands of the users as soon as possible in order that any faults may be found and corrected before much damage is done.

Unfortunately, changes in process are frequently made in production without sufficient check. Where changes are made after thorough check there is still danger. We have never found it possible to exert enough pressure for the maintenance of paper standards and paper methods so that no bright foreman or superintendent would deviate from them on his own initiative and without written authority. Every effort should be made, and is made, to maintain these standards. It should be the policy of the management that it is better to continue an old standard until a change is properly authorized rather than to take chances on changes which have not been properly checked.

I suppose that any paper might be closed with the statement that good judgment consistently and sympathetically applied is necessary for the success of any phase of the business, but I do not believe that there is any other place where as much profit can be made or as much money wasted as in changes in process and the development work necessary for them unless such good judgment is used.

The man who is responsible must be sufficiently high in authority to see the

picture from the standpoint of the sales, as well as the manufacturing and the technical departments, and must keep in close contact with the work being done by the man delegated to look after any particular project. The expenditures should be carefully watched to see that they are economical without being stingy, and a personal interest must be displayed which will keep up the enthusiasm of those doing the experimental work. Even with the best control of this type many good ideas will be lost, money wasted upon many poor ones, and after it is thought that the job has been thoroughly done faults will develop which may have serious results.

We also quote from the paper by C. A. Purdy.

During the past few years important improvements have been introduced in the Condenser Department of the Western Electric Company as the result of a comprehensive development program.

These improvements are typical of those introduced throughout the Manufacturing Department and serve to illustrate the application of principles and methods employed in the management development activities of the company.

A summary of the results of the condenser developments is obtained by comparing quantities and costs of materials necessary to produce the 1930 condenser requirements by 1925 methods and by present methods. The weight of condenser paper is reduced from 850,000 pounds to 280,000 pounds; the weight of tinfoil from 1,400,000 pounds to 480,000 pounds; the cost of these materials from $1,700,000 to $640,000; the cost of mica from $1,275,000 to $500,000. Also the floor space occupied is reduced from 15,000 sq. ft. to 10,000 sq. ft. The overall improvements have effected savings aggregating more than two million dollars annually, and have made possible redesigns wherein the condensers have been reduced in size to less than one-third of their former volume. This effects important space economies in the telephone plant with resulting additional savings to the system.

Not all of these advantages were anticipated at the outset, in fact few definite ideas had been formulated as to what improvements could be made or what economies could be realized. However, based on general principles that have proved quite trustworthy, the Condenser Department presented a profitable field for development effort.

The expenditure for materials and labor was great enough so that nominal cost savings would adequately support a comprehensive development program. Although the various manufacturing operations had been sufficiently laid out by the Planning Organizations, comprehensive development studies had not been conducted. The forward picture indicated that condensers would be needed in greatly increasing numbers, and that quality requirements would become more and more exacting.

Based on this outlook a corps of engineers was built up to study the condenser job in detail, and according to expectations as this study progressed and the engineers became thoroughly familiar with details of the job, plans for mechanizing hand operations and plans for more effectively using the materials were conceived and developed. One development opened the way for

another until almost every phase of the condenser process had been changed, and it is certain that further developments will result in further reduction in cost and improvement in quality.

The preliminary studies involved only small expenditures of time and money, but provided sufficient data from which to formulate definite plans and to forecast with fair accuracy the cost of a definite project and the saving to be realized.

An interesting study is the comparison of predicted cost and predicted annual savings, based on requirements at the time the studies were originated, with actual cost and actual annual savings based on present requirements of all the condenser development studies conducted under this program. The totals in this comparison are shown in Figure 1.

[*Note:* Figure 1 gives the following totals:

Predicted cost	$104,500
Predicted annual saving	$531,000
Actual cost	$112,000
Actual annual saving	$2,113,000]

The increase in actual saving over the prediction is largely the result of increased requirements, although partially caused by better realization than estimated, and by enlarged scope of study which also accounts for most of the increase in actual cost of the developments over the estimate.

This chart and the figures quoted above are based on studies applying to the two general classes of condensers manufactured, that is, those using mica as a dielectric and those using paper as a dielectric. However, the following illustrations which are intended to give a more detailed picture of the nature of the developments and the results are confined to the manufacture of paper condensers.

Since in time sequence the developments were overlapping, it appears best to describe them in the order of occurrence in the manufacturing process and give first a description of the structure and the materials used in a standard paper tinfoil condenser.

You will recall that an electrostatic capacity of a condenser is formed by two conducting plates separated by an insulator. The capacity which is a measure of the electrical charge that the condenser will retain under a given potential, depends upon three factors; the area of the dielectric separating the plates; the thickness of this dielectric, and its specific inductive capacity. The materials used in the standard paper condensers manufactured by the Western Electric Company are as follows: So-called tinfoil is used for the conducting plates. This is a very thin and delicate material only ¼ of 1/1000 of an inch thick, having a composition of 85 per cent tin, 12½ lead, and 2½ per cent antimony. The insulating or dielectric material is a very high grade paper, also very thin—the thickness having recently been reduced from ½ of 1/1000 to 0.4 of 1/1000 inch. These materials are obtained in rolls. In the standard condenser tested at 500 volts D.C. two sheets of this paper are used between foils, two sheets of foil and a total of four sheets of paper

being rolled together to form a condenser unit. Thin tinned brass strips are placed in contact with the foil to form terminals for the electrical connections. To afford proper electrical characteristics, these wound units are thoroughly dried and then impregnated in a suitable wax, the wax formerly used being a paraffin compound and the wax now used being a chlorinated naphthalene. After impregnation the units are cooled under suitable pressure, which expresses surplus wax from between the foils and suitably forms the units. Exterior terminals are then soldered to the brasses and the unit is completely sealed with a moisture proof compound in a tinplate can. The several steps in the manufacturing process, that is winding, baking and impregnating, process testing, and potting and the improvements made in the equipment and methods will be shown in more detail in order of occurrence.

A hand machine was used to wind the paper and foil into the condenser unit at the start of the development program. It was a simple device consisting of suitable foil and paper spool holders with tension arrangement, an arbor which was turned by hand and a counter for determining the number of turns of paper and foil wound on the arbor. Two units were wound simultaneously. The winding cycle was made up of approximately 20 seconds straight forward winding time and a minute and 20 seconds incidental time used in starting paper and tinfoil, placing terminals, removing units from the arbor, etc. Considerable discussion centered around the question of the advisability of motor driving these winding machines. The preliminary analysis based on the time distribution as given above indicated that very little would be gained by motorizing the machines, since the incidental operations would remain the same and speed of winding could be only slightly increased because of the delicate nature of the materials. Furthermore, if the winding speed were doubled only a ten per cent reduction in time cycle would be realized. The result was that when new winding machines were required for capacity increases the machine was redesigned to conserve floor space and afford some greater convenience for the winding operator, but the hand power feature was retained.

No greater output was obtained from this machine than from the old style machine. It did, however, lend itself better to motorizing. One machine was so equipped, and observations made relative to winding output and quality of condensers with particular reference to the capacity of the units. Results were encouraging. Although the winding speed was only slightly increased the output was increased from 480 units per day to 550 units per day, mostly because the operator experienced less fatigue and both hands were free for the various operations incidental to starting and finishing. In addition it was found that through the more uniform winding a smoother unit with fewer wrinkles and fewer margin irregularities was obtained, which increased the electrostatic capacity of a given length of foil and paper approximately 2½ per cent. Since it was desired only to retain the same capacity, a corresponding reduction in quantity of foil and paper resulted which made a more worth while saving than the increased output. This adequately justified motorizing the machines and opened the way for further winding developments that have

resulted in much greater output and additional saving in material. Racks are placed at the sides of the winding operators in which the units are placed as wound. These racks hold 240 one-microfarad units each, and are the handling containers throughout the baking, impregnating, and pressing operations.

The racks of units are removed from the winding machines to an air-operated press where the units are subjected to a pressure of approximately 40 pounds per square inch of surface and blocked in this position for subsequent treatment. After this pressing operation the racks of units are pigeon-holed in carrying racks holding a total of more than 4,000 condenser units. This load of units is easily transported and handled, and the operator removes the load of units from a special truck into a front opening vacuum tank for baking and impregnating.

A battery of five tanks is used. Each tank holds two of the large racks giving a total capacity of 40,000 one-microfarad units per load.

In these tanks the units are brought up to baking temperature and subjected to a vacuum of approximately 28 inches of mercury for preliminary drying. After the greater part of free water is removed the pressure in the tanks is reduced to within ¼ inch of absolute vacuum, which effectively removes the final traces of moisture. After the drying is completed the impregnating wax is admitted while the vacuum is maintained, and the units are left in the wax under vacuum until the capillaries of the paper are thoroughly filled with wax.

Vacuum pumps are used in tandem to obtain the high vacuum for finish drying and impregnating. A vacuum within ¼ inch of absolute is not considered high in laboratory practice, but in an installation of this size and character is obtained only by exercising great care in the design, construction, and maintenance of the equipment.

Other equipment is used for further pressing the condenser units after impregnating. The lot of 4,000 units is still maintained and is handled with little expenditure of time and effort between operations. Multiple pistons are at the back of this special press which register with the holes in the end of the individual racks. The racks are held in place by the strongly bolted door which resists a total pressure of about four tons. The pistons are actuated by a small hydraulic hand pump, the pressure being increased as the units are cooled according to an optimum temperature pressure scale established by extensive experiments. For best results this pressure must be regulated so as to leave sufficient wax in the unit to seal it against moisture and at the same time express the excess so as to give minimum distance between foils for maximum capacity.

The combined improvements resulting from these treating and pressing methods have been among the largest factors contributing to the total savings. These methods also illustrate well the interrelation between developments. The severe pressing methods, while greatly increasing the capacity of the units, make adequate drying and impregnating very difficult. The high vacuum system provides for adequate baking and impregnating even under this ad-

verse condition. In this way quality is maintained and at the same time large savings are effected.

The old system of baking and impregnating has not been described, but it will be sufficient to say that it required much more handling of units and was much less effective in the results obtained.

After the units leave the press electrical tests are applied to establish quality before further work is expended on the unit. This process testing of units was formerly done as a hand operation by use of test equipment. A five-second voltage test was applied and a check made to determine whether the capacity value was at least one microfarad. Because of irregularities in the thickness of the paper and other uncontrollable factors in the process, the capacity varies considerably and the former practice was to hold the average high enough so that units of lowest capacity value would meet the requirements for a condenser coded one microfarad, or so that any two units paired would meet the requirements for a condenser coded two microfarads. The capacity of the units above one microfarad represented a safety margin and was waste material if the average could be held close to the nominal value.

The process testing is now done on a very interesting machine which automatically applies voltage and insulation resistance tests, rejects the defective units, and measures and classifies the good units according to capacity into thirteen groups. This classification eliminates the need for the safety margin. By properly pairing the units from the high capacity channels with those from the low capacity channels for two microfarad condensers and using the units near the mean for one microfarad condensers, the whole capacity range may be reduced and the waste eliminated.

The units are placed in a chute by the operator, this being the first individual handling of units since they were placed in the rack at the winding machine. From the chute the units are automatically carried to a turret where the terminals are clamped so that as the turret indexes electrical connection is made for the various tests.

The part of the machine which measures and selects the units for capacity is a standard microfarad meter having the regular scale replaced by commutator segments and a pressure bow arranged to press the meter needle into contact with a segment when a capacity measurement is made. In this way an electrical circuit is set up which operates a system of relays. The relays in turn control circuits which operate electrical solenoids at the discharge end of the machine which stop the carriage and cause the unit to be dropped into the proper channel.

The capacity range as formerly maintained was from 1.00 to 1.25 microfarads. The range as now maintained is from .90 to 1.15 microfarads. This reduction is made by using less paper and foil and represents nearly 10 per cent saving in material.

In order that the condenser will retain its electrical characteristics and not deteriorate with age it must be perfectly sealed against moisture. This is accomplished by potting the unit in a tinplate can, where it is completely sealed with a waterproof compound. This compound must be poured at a

temperature between 350 degrees and 400 degrees Fahrenheit and is very viscous and difficult to handle. It was formerly necessary for operators to carry this hot compound in small pots from the melting tanks and pour it by hand into the condenser cans. This method has been replaced by special equipment which dispenses the compound into the condenser cans as they are carried on a conveyor. The unit is then pushed into the compound and the exterior terminals and finishing operations completed on a progressive assembly line.

The machines and processes described have changed the manufacture of standard paper condensers from hand operations to automatic or semi-automatic operations throughout, and the material saving and size reduction of the condenser units are perhaps the most striking of any of the results obtained.

[*Note:* The following tabulation gives the length of foil and paper in standard one microfarad unit in various stages of the development program:

238 inches—old method
198 inches—after introduction of hydraulic press and power winding machine
162 inches—after introduction of prepressing
150 inches—after introduction of automatic sorting
128 inches—after replacing 0.0005-inch paper by 0.0004-inch thick paper
95 inches—after introduction of chlorinated naphthalene for impregnating wax]

These illustrations are typical of the development activities that have been conducted and will be conducted throughout the Western Electric Organization. The overall results indicate clearly the value of development effort, and it may be expected that similar results are possible in almost any organization. However, it is well to note that an outstanding factor in obtaining such results involves first the development of a specialized Engineering Personnel and that such results may not be expected from brief studies conducted here and there by engineers who have not acquired a comprehensive and detailed understanding of the entire project, however high their general proficiency. The possibilities in the interrelations of the baking, impregnating, and pressing developments, for example, would have been recognized only by engineers thoroughly familiar with the specialized problem. The cost of development is a function controlled by the degree of complicity of the undertaking, whereas the saving resulting from development is a function related to the total expenditure for labor and materials,—the maximum possible saving of course being less than the total expenditure. Based on the experience drawn from the developments described, an outline for a comprehensive manufacturing cost reduction development program would require briefly, first, the development of a specialized engineering personnel, second, the intensive application of this personnel upon a project where nominal cost savings would adequately support the development, and third, the continuation of this application over a sufficiently long period to establish the various interrelations and further applications of the first developments, for therein will be found the largest economies.

CHAPTER XIII

PRODUCT DEVELOPMENT

Any product, as noted earlier, must be constantly improved if a high quality is to be maintained. Product development covers the field from the invention of an entirely new product to minor changes made in the design of an existing product to improve its performance or to facilitate its manufacture.

Machine Design

Effective machine design involves two distinct tasks. The first is the functional design, the second the production design. As pointed out before, the functional design consists primarily of the selection or the improvising of suitable mechanical motions and their arrangement to accomplish a given purpose. Some consideration must be given at this point to the structure of the parts. This is because an experimental mechanism must be made and tried out so that we can correct or perfect the critical elements of a new mechanism. Many of these must be established by experiment. Nevertheless, the primary purpose in all this is to arrange a combination of mechanical motions to accomplish a set purpose.

The production design consists of a critical study of the final functional design to arrange and design the details of the product so that they can be made with facility on the available manufacturing equipment. This involves the development and application of many shop standards, the critical selection of the materials, the determination of suitable tolerances for all the critical functional surfaces. It involves also all the detailed tasks needed to collect and give to the manufacturing departments the information they require to carry on the production promptly, precisely, and intelligently.

As the requirements of the mechanism become more severe, because of higher speeds, greater loads, necessity of minimum weight, quietness of operation, or for any other reason, the need of more nearly exact analyses of many components becomes more acute. Although the functional design is necessary as a start, it is the adequacy of the production design which largely determines the commercial success or failure of any new product.

Today, few plants recognize this two-fold nature of design. Too often the attempt is made to solve simultaneously the two types of

problems involved. It is seldom that this is done adequately. The many changes which are made during the initial stages of the production of a new mechanism to correct obvious faults of design or to "facilitate manufacture" are good measures of the shortcomings of the practice of combining too much at once. Eventually, if production of the unit continues long enough, an effective production design will be evolved, but at the cost of many expensive changes and of disturbing delays in production. Such conditions also widen the rift which unfortunately exists in too many plants between the manufacturing departments and the engineering staff.

There are several schools of thought as to the proper distribution of trouble between the engineering staff and the production departments. What may be called the "practical" school takes the position that as long as the engineers have specified the final results required, it is none of their business how much trouble the mechanics meet in trying to get them. Even though ten or one hundred hours' additional work by the engineers would save several times that amount of time in the shop, "let the men in the shop worry—it is good for them."

The opposing school of thought, which may be called the "impractical" or possibly the "theoretical," believes that the work of the production design is not finished until the engineers have done everything in their power to uncover all pertinent information, and have arranged it in such shape that the shop can use it directly. The shop has enough troubles of its own, and should not be distracted from their attempts to solve them by the additional load of trying to complete the engineers' or designers' tasks. Even here, there is a difference of opinion as to the best procedure. The engineer often has a choice of two courses: the first will give a reasonably accurate solution that is simple for the shop to use; the second will give a more accurate or exact solution but it may involve the shop in more difficulties when they try to carry it out. Which course should be followed? This is a matter of the relative functional importance of the point in question. If the operating conditions are not severe and either solution would be adequate, by all means choose that solution which is easier for the shop; but if the conditions are so severe that they are approaching a limiting case, then neither the engineering staff nor the shop should spare any pains to make the most of the best possible designs, techniques, and materials which are available.

The trends of today indicate a growing demand for the seemingly opposed requirements of higher speeds and greater loads coupled with more reliability and greater quietness of operation. These demands are met in part by improved materials, better balancing, more nearly

perfect machined surfaces, and more intensive attention to details of design. This should also include a definite organization of the detailed tasks involved, including the rigid analysis of both the kinematics and dynamics of the conditions of operation.

The major objections to the thorough analysis of the mechanisms are the amount of time required to make them and the dearth of individuals who have both the ability and the inherent desire to do such work. If each new project must be started from the beginning, the time to carry it through may be excessive for a single application. If, however, we can build up a foundation of general solutions of different types of mechanism, then the specific task for any given project will be to arrange the general solution for the particular case, and solve. The same method of attack is possible for many other problems of product development. If we must start with nothing, and take the time to collect and arrange all the information that we should have for the solution of a specific problem, the time required to do this will be excessive. On the other hand, if we first build up our sources of information for ready reference, and add to them from our increasing experience, then the time required to select and apply this information will be greatly reduced.

We will now consider the problem of product development under the following headings: (*a*) entirely new product, (*b*) development of custom-made product of standard type, (*c*) radical redesign of existing product, and (*d*) minor redesign of existing product.

Entirely New Product

The development of an entirely new product starts with the inspirational or functional design. After the first layout has been completed, time and money can often be saved by checking as many of the new and critical features as possible with simple experimental tests. These tests should be made before the construction of the complete experimental model is started. For example, after the first design of a new gasoline engine is completed, a single-cylinder assembly is made and tested for performance before any work is started on the construction of the complete engine. The information gained from these simple tests may lead to changes in design of greater or less extent. The test cylinder assembly is then changed or rebuilt so that the influence of the alterations can be checked. Only after the test cylinder assembly has proved to be satisfactory is the functional design of this element of the engine design completed.

Similar experimental tests of elements of many other products can be made to advantage. A new product is seldom if ever completely

new in all respects. Much of the construction will employ old and tried mechanical elements whose performance characteristics are reasonably well known. Few, if any, experimental tests are needed for such elements unless the speed range is increased beyond the usual range, or unless new combinations of materials are used or much heavier loads are imposed. With some thought and a little ingenuity, relatively simple test set-ups can be devised to obtain actual performance data about new and experimental features of the design. With this information available, the first experimental model will start closer to its ultimate functional design than it could otherwise start.

After the first experimental model has been built, actual tests usually uncover many opportunities for further improvement. This will lead to many changes, and may possibly lead to the construction of a second, and sometimes a third experimental model. No plans should be started for actual production until the functional design has definitely proved itself wholly adequate to meet its purpose. Whenever the work is done in the plant that is to produce the product, this functional design is the responsibility of an experimental department or of a machine design group. It is then a part of the product engineering.

After the functional design has been accepted for manufacture, the production design group should then put it in good shape for production. From here on, the production engineering staff is responsible for its further progress. Parts of the personnel may be transferred or loaned from one group to another, either by reason of their personal abilities or to increase their experience. The same person may perform all the different tasks from the functional design to the tool design, for example, but he should deliberately take up each successive task as a specific job, and should never try to do more than one type of work at a time.

Development of Custom-Made Product of Standard Type

The product development of custom-made machinery of some general standard type is one of the most complex problems for which to find an adequate solution. This is because the number of identical units to be built is small and we can afford to make little more than a functional design. There are, however, many opportunities of simplifying the work of this design by establishing definite practices or standards for the design of many of the common types of elements and mechanisms, and by the standardization of many individual component parts and surfaces. In many respects, such standardization is a form of production design. The original selection and later improve-

ment of these standards belong in the category of product development. Such development should be divorced from the functional design, and all development efforts should be applied directly to the improvement of the standard practice.

The separating of development from routine machine design is seldom or never done. Casual use is made of standard component parts and surfaces. Each new design may follow to some extent the design of a previous machine of similar type, but little effort is made to select from past designs the construction that has proved itself to be both best in operation and easiest for the shop to make, and to establish this as the standard design practice which must be used until a better one has been developed. Instead, many designers of this type of product have little knowledge of the relative and actual performances of the different designs in actual service in the hands of the customers. Many of these designers consider that each new job is an opportunity to work out new ideas, and thus combine a large development project with a small amount of functional design, and they make little use of standard component parts. As a result, the estimated time for design is greatly exceeded, and the shop often finds itself engaged in a large experimental development project which in turn often causes the time estimates for the shop to be exceeded.

Product development and design problems of this character exist in the design and manufacture of machinery such as large printing presses, packaging machines, special automatic drilling machines, steel mill machinery, paper-making machines, special automatic multiple-station machines, and many types of large machine tools. The design of any one type of machinery can be broken down into separate elements and types of mechanism. These elements may be of different sizes and may be used for many different purposes. However, if sufficient thought is given to the problem and a definite effort is made to solve it, some definite standard of design can be selected from previous designs for each of these elements.

One difficulty which is frequently met in any attempt to organize design activities along systematic lines is the natural perversity of the human factor. In the larger plants where the design department is divided into groups, each of which works on a special type of application of the product, each group believes that its own solutions of these design problems are the best and that the use of any solution made by another group is impossible and detrimental because those solutions are always much inferior to their own. Furthermore, each group works continually to find new solutions, which are not always better than the old one, and often seems to feel that the number of

new or different solutions it can find and use is the most important measure of its ability as designers. The same relations exist in the smaller plants between some of the individuals of the design department, and between different members of the same group in the larger plants.

The first step towards the correction of such unsatisfactory sentiments is to study the product and break it down into separate elements and types of mechanism. This breakdown may not be complete at the start. The more common or the more important elements may be studied first, then others can be added to the list as the opportunity is found to carry this work farther. The experience gained in the first studies will prove valuable to the more effective analysis of the other elements. The next step is to select from past designs the best that is available for a particular element, both functionally and for ease of manufacture. This information must come either from a study of actual performance in the field, or from simple experiments, or from both. The solution which is chosen should be definitely set up as a design standard. A further step is the adoption of a fixed policy of product development, one which will be devoted almost exclusively to the improvement and perfecting of these design standards.

If a designer, when working on a particular design project, has an idea that may develop into an improvement of the existing design standard, his idea should be made a matter of record for consideration later as a possible product development project. No time, however, should be spent on it by the designer until he has completed the definite design project in hand. The further consideration of this idea and all others that may be submitted from any source should be handled as actual product development projects. For any schemes that appear to have merit, simple experiments should be made first to test the value of the idea. If the results of these experiments are encouraging, the construction may be applied to some experimental machine in the shop. If it is successful here, arrangements can be made with some customer so that it can be applied to equipment in actual service and receive a long-time test. If the new design proves to be better than the existing standard practice, this practice should be revised accordingly. By this or in a similar way, development projects and costs can be kept separate from those of routine design, and both types of work can be kept under better control.

On many of these specific design projects there will often be some amount of functional and development work because of the unique application of the equipment. If this were not so, there would be no need for this custom-made product. This work cannot be separated

from the work of the routine design. A careful analysis will usually show that the amount of the development is a relatively small part of the total amount of design.

Another factor of product development, which is not confined to this particular type of design problems, is the kinematic and dynamic analysis of different types of mechanism. This is an almost untouched field. A few engineering departments for products which must meet critical conditions of operation have established separate analytical sections where this kind of work is carried on. This type of engineering work is sometimes coupled with that of an engineering research or experimental department and a small amount of it, that is, small in relation to the amount that should be done, is being conducted by many research committees working under the auspices of some of the national trade and engineering organizations. Among the projects are the study of lubrication and bearing design, fatigue and other physical properties of materials, plasticity and creep of metals, influence of combined stresses, load distribution on screw threads, strength of gears, etc. Much private research is being conducted on many other projects such as cams, linkages, critical speeds and vibration dampening, ball and roller bearings, and couplings. Even with reliable published data available, the individual manufacturer would do well to make some simple tests of his own on any of these items which may be of critical importance to his own product. He can then check the conditions for these elements on his own product and obtain some measure of the effectiveness of his own materials and practices. As an example, one large manufacturer was able practically to double the operating speed of some of his product as a result of thorough analyses made on the critical elements of the designs, followed by simple experiments to check the validity of the analysis. With this definite information as a guide, these critical elements were redesigned accordingly. The improved product operated more smoothly at the higher speeds than it did at the lower original speeds.

In this field of custom-built equipment, product development may be set up as a separate activity with a permanent staff in the larger plants. In smaller plants, it can be organized as fill-in jobs for the engineering group, and the work can be done when time is available. Attempts should be made to develop specialists for this work, that is, the same type of development work should be given to the same man so that he can become thoroughly familiar with the specific element and its problems of construction and operation. Even when the creative work of product development is done as fill-in jobs, at least one man should be permanently assigned to this work to keep a record

of the potential projects, and to keep the standard design practice records up to date.

Radical Redesign of Existing Product

A radical redesign of a product may be made because of the demands of customers for additional features of operation which involve major changes, or to match the progress of competitors, or to take greater advantage of some new process developments, or to reduce the factory cost of production by a reduction of variety of product and the use of more parts in common by the different sizes of the product. A small amount of functional design may be involved here. The majority of this redesign, however, is production design.

Mention has already been made of the increased demands made on the performance of machine tools by the introduction of high-speed cutting tools and the recent introduction of the cemented-carbide and tungsten-carbide tool bits. No essential functional requirement, as regards the combination of mechanical movements needed, is involved in this redesign. Parts must be made stiffer, heavier, and stronger, although hitherto neglected conditions of unbalance must be corrected because of the increased speeds. Some rearrangements of parts or units are necessary, and other changes are made in the controls. Hardened-steel parts are substituted for soft-steel parts in many places, and this requires a change in the manufacturing methods used in the shop, but all these elements of change are of the same type as those of production design.

Redesigns are made to increase the speed of operation of the product. The detailed requirements of a product, operating in a given speed range, become established after continued experience. The speed range may be increased little by little with no apparent change in the requirements. At some time, however, a further increase in speed introduces new conditions of operation which were not present at the lower speeds. Considerable experience with the operation of the mechanism at the increased speeds is needed before these new problems are solved. Solutions which are adequate for the lower speed of operation often prove to be entirely wrong for the higher speed.

There appear to be three distinct speed ranges for any type of mechanism. These, for lack of better terms, will be called the low-speed range, the intermediate-speed range, and the high-speed range. In the low-speed range, the actual performance appears to follow very closely the dynamics of rigid bodies. The influence of the elasticity of the materials and their local deformations is small, and forces set up by variations in the momentums of moving masses appear to vary

directly as the masses and with the square of the velocity of these masses. Static balance is of little importance at the lowest speeds, but may need some attention at the upper end of the low-speed range.

The actual position of the transition zone from the low-speed range to the intermediate-speed range has not been established except by actual experience with specific constructions. Thus, for example, this transition zone appears to be between nine hundred and eleven hundred feet per minute peripheral speed for paper-making machines, printing presses, and gear drives. It is still a question whether the peripheral or the rotational speed is the controlling factor. Probably both of them, together with the disposition of the moving masses, play a definite part in the performance.

In the intermediate-speed range, elasticity of materials and the small local elastic deformations begin to make their influence felt and in this range, as a rough average, the force set up by changes in momentum appears to vary with the square root of the masses and directly as the velocity. Elastic deformations increase the time and thus reduce the intensity of the maximum momentary dynamic loads. Static balance is important, and becomes increasingly so as the speeds increase. Dynamic balance may be of minor importance at the lower end of this range, but becomes of primary importance towards the middle and upper end. Harmonic vibrations and critical speeds begin to make their appearance here, and become increasingly troublesome with the higher speeds so that vibration dampening must be introduced in many places. More attention must be given to lubrication, frictional heat, fatigue of materials, and wear in this intermediate-speed range than is given to them in the low-speed range. The transition from this speed range to the high-speed range is more gradual than that from the low-speed range to the intermediate-speed range.

In the high-speed range, the elasticity of the materials and the local deformations of the parts have a pronounced influence. These deformations tend to make the forces set up by changes in momentum of moving masses approach an asymptotic value so that these forces appear to be independent of the masses and of the velocities. In other words, the changes in these dynamic conditions over a wide range of speeds are so small that the values may be considered and used as constants. All this leads to the seeming paradox that a construction which is statically weaker than another will often be dynamically stronger when operated at high speed. This results when the elastic deformation is greater, so that the force set up by a change in momentum has a longer time in which to act. The actual masses of moving parts must generally be reduced to a minimum, static and dynamic balance must

be nearly perfect, critical speeds must be avoided as operating speeds, vibration dampening must be applied in many cases, fatigue characteristics of the materials used must be known, and many other refinements unknown to the lower-speed ranges must be made in this high-speed range.

Our knowledge of the dynamics of elastic bodies is extremely limited. At present, we must rely upon empirical values and relationships obtained from experiment and experience for the design of mechanisms operating in the intermediate- and high-speed ranges. So when the increase in speed required on the product moves it from the low-speed range into the intermediate-speed range, we meet many unfamiliar problems which must be solved before our production design is adequate.

Another type of product development which involves a radical redesign consists of the redesign of a group of similar products of different sizes or capacities so that many more component parts are common to the several models. This is essentially a problem of standardization. Such a group of similar products is naturally developed over a period of time, and the different models are often designed by different men, each with his own notions and pet constructions. In these cases, a complete redesign of the whole group at the same time is the only way to obtain the greatest benefits of such shop standardization. Much depends on the ability of the designer and on his personal enthusiasm for this type of work. Such standardization is not a matter of routine, but it is creative work of a high order. As an example of what is possible along these lines, some years ago a manufacturer of gasoline engines decided to redesign a group of six motors of different sizes into a coordinated group, and to arrange these designs so as to use as many component parts in common as he could. The designer in charge of this project was enthusiastic about the possibilities, and when the job was done, the total number of different component parts needed for the construction of the six engines was only slightly more than twice the number needed for a single engine. The influence of the greater production of a smaller variety of parts was reflected in a reduced factory cost of production.

Minor Redesign of Existing Product

Minor redesigns and changes in an existing product are made almost continuously in the course of production. For example, one large organization which operates several plants and manufactures a wide variety of products handles about five thousand change slips a week. These changes involve minor changes in equipment, or changes of

materials, or changes in operating specifications, or minor changes in the product. Some are made to correct unsatisfactory performance of the product, some are made to introduce new features on the product, some are made to adapt the design of the product to use a new process more effectively, some are made because of a change in materials, but many are made to facilitate manufacture. This last type of change is, in other words, a further step in the completion of the production design. A large part of the routine work in the engineering department of a plant making a specialized product is of this general character. It is the gathering together of many loose ends which have been hitherto neglected.

Field Research

"The proper study of mankind is man." The proper study of any product is its behavior in the hands of its users. Laboratory tests have their value, but the results obtained there cannot be accepted as conclusive until the results have been confirmed by the experience of actual practice. Every effort may be made to have the laboratory set-up simulate the service conditions, but all may not be included or more care and a closer control may be exercised during the tests than is given in service, so that the test results may be misleading. For example, a small tool manufacturer decided to give up the manufacture of twist drills so as to devote more attention to the production of reamers and other types of cutting tools. Arrangements were made with another drill manufacturer to furnish drills marked with the trademark of the first company. A large manufacturing company, an old customer of the first small tool plant, had established the practice of making definite tests each year of different types of small tools furnished by different manufacturers, and of selecting that maker as the supplier for a particular type of cutting tool whose product showed up best in these tests. The following year, when the tests of drills were made, the drills of the first company, as had been usual for years, gave by far the best results of any of the several brands which had been submitted for test. The drills of the second company ranked about number six in a field of about eight competitors. The only difference in the drills that had ranked first and sixth in these tests was the name that was stamped upon them.

Many elaborate set-ups are made in laboratories, and many expensive experiments are made to get information about the behavior of a product under service conditions. A large part of this is entirely unnecessary. The conditions which need study already exist in the plants of customers. With a little planning and the provision of simple

testing facilities that can be applied to the product in service, and with a member of the staff who has insatiable curiosity, arrangements can be made to conduct tests or to observe the performance of the product while it is in actual service in the plants of users. Here are enormous research facilities that have been almost entirely ignored.

As an example, a company had developed a material which they believed might be useful, in addition to many other applications, as a bearing material on brass-rolling mills. An appropriation of several thousand dollars was made for experimental work and research to test this idea. The suggestion had come from an outside source, so when the appropriation was granted, the engineer in charge of the development conferred with the originator of the suggestion as to ways and means of making the laboratory tests. This engineer was advised to get in touch first with a brass mill and find out the sizes of the bearings for one of these mills; then to make up bearings for the mill, and to send them out with an observer to study their performance in actual service. This was an unorthodox procedure to the engineer, but after considerable discussion he accepted it as an adequate one. It took him nearly a month, however, to sell to his own organization the idea of using the plant of the potential customer as the research laboratory for the project. He finally succeeded, however, and the experiments were made under actual service conditions with the full cooperation of the staff at the brass mill. The tests were completed, the desired information was obtained, the material proved to be excellent for the purpose, and only a small part of the appropriation was spent to carry through the project.

As another example, a manufacturer of steel-rolling-mill equipment needed more definite information than was available about the actual loads on the roll-neck bearings of steel-rolling mills. He needed it to carry through a new development of his product. A large appropriation was made for the start of an investigation to provide testing facilities and to start laboratory tests. Many people were consulted for information and advice about the testing equipment and tests that might be made. One suggestion was that they first develop some simple strain gage that could be applied directly to a rolling mill in operation. They should then send a man out into the field to use it there. A simple and effective device was developed, and after about six months' use in the field, a large amount of reliable and useful data was collected which enabled this company to make many valuable and effective improvements in the design and performance of their product.

It is a good policy for any manufacturer of equipment used by others to conduct periodic surveys of the performance of his product in actual

use. Designers should be given the opportunity of observing such performances of the products they design. Whenever possible, they should be given the opportunity to learn to operate it themselves. For example, one printing-press manufacturer, as a start towards the design and development of some radically different features of construction and operation of printing machinery, sent the engineer who was to carry through this development into a commercial printing establishment for six months, to give him training as a press operator. With this background, the new development was carried through in a remarkably short time. The six months' time of the engineer in the printing department was far from wasted.

Reports of salesmen, sales engineers, and service men should always receive careful attention. What these reports say may be quite different from the actual conditions. The same is true of complaints from customers. All should be investigated, and the grounds of the complaint identified. Cause and effect as they are reported and as they exist may be widely different, but every contact with and study of actual service operating conditions will uncover unknown facts which the production plant ought to know.

CHAPTER XIV

SUMMARY

Production engineering is only one type of activity out of the many which are needed to operate any manufacturing organization. In order to give a more nearly complete picture of such an organization and to indicate the role of production engineering, a brief summary follows of the over-all activities of a production organization. These activities may be grouped and organized in many different ways. For the sole purpose of indicating the place of production engineering among them, the following divisions are given.

General Management

Under the heading of general management, we will include all those functions which establish general policies, operate the business activities as distinguished from those of engineering and production, coordinate the work of the organization as a whole, provide information and service of a general character, and direct the general operation of the plant.

Thus general management, as used here, would consist of a chief, who is the directing head of the organization whatever his official title may be, and the heads of the various divisions whose decisions determine the general policies or direct and control them. Among such divisions are the following:

(*a*) *Financial division*. This department may be headed by the treasurer of the organization and its duties include all financial operations of the company. It must collect and pay all current accounts, secure working capital for the operating expenses of the plant, including the payrolls, and conduct negotiations with the banks or other sources of funds when necessary. It operates the accounting department, including the factory cost accounting, makes up budgets from the estimates submitted by the other divisions, makes out tax returns, and draws up the financial statements required from time to time for various purposes. Factory cost accounting and budgets, ignoring salaries, are the two items here which directly affect the activities of production engineering.

(*b*) *Legal division*. This division handles all legal matters such as legal advice on governmental regulations, and drawing of contracts for

the organization. There is a patent section to defend suits for infringement, apply for patents, and negotiate licenses for the use of patents held by others. Great care must be exercised in order that existing patents of others are not infringed by the product which is made or the processes which are used. This often requires an extensive patent search before a new product can be accepted for production. In some plants, all new designs must be cleared through the patent department before any steps are taken for their production. In turn, new designs or new processes which have been developed may need to be protected by patents. The action then depends upon the general policy of the management. These patent activities of the legal department are those with which production engineering makes most contact.

(c) *Sales division.* This division may also control advertising and customer service activities. Production engineering has a direct interest in all the activities of this division. Promises of delivery are made and prices are quoted which the production department is supposed to meet, no matter how unreasonable they may seem to be. Delivery promises are generally the most acute problem. The salesmen may be forced to shave the time of delivery to secure an order, then the production department is blamed for failure to meet it. The production department should not be held responsible for any delays in delivery unless they themselves have made the definite promise. On the other hand, production departments have been known to make promises which they were unable to keep. Sales engineers are often attached to the sales division who work in close cooperation with the production engineering group.

The advertising department and the engineering department usually find a great deal of difficulty in understanding each other. The advertising department appears to be always looking for the spectacular, and to have a tendency to make general statements of the merits and abilities of the product which imply much more than is actually stated. Any reservations or limitations to these general statements that may be suggested by the engineer, in order to keep them within legitimate bounds, are vetoed by the advertising department because they weaken the force of the publicity. Sometimes the major effect of such publicity is an almost endless amount of correspondence between the engineering staff and potential customers in the effort to keep them from going astray and to help preserve the reputation of the organization.

The question of price is one for the general management to decide. The production department will give the amount of material and the

hours of work required to make the product; the management must decide what return they want on the particular order.

(*d*) *Personnel division.* This division establishes the general policies governing methods of wage payments, controls the official or legal labor relations, etc., and may also keep the personnel records and operate the employment office. It generally fosters employee activities and associations of many kinds. It can logically direct the operation of suggestion boxes and the follow-up of suggestions, assisted by engineers and others whose opinions may be useful. It may also be the headquarters and may direct foremen and apprentice training courses and all other educational and training activities. It is also the logical director for all general campaigns for the reduction of accidents and of waste.

(*e*) *Standards division.* This division should instigate and follow up standardization projects in every phase of the work of the organization. Special groups should be organized for each specific project and should include representation from every group involved or affected by the proposed standard, including the outside supplier if a purchased item is involved. This division should also keep in close touch with all such activities of national engineering societies and trade associations where work on standards of interest to the company is under way. Opportunity should be given for various members of the organization to serve on such general standards committees whenever possible. Such work is distinctly educational for the individual, since all phases of the design, manufacture, and use of the material in question are discussed fully by the leading authorities on that subject.

This division should set up and direct a well-defined standardization policy for the organization and keep a complete record of this work. It should also build up a file of all published standards which are of interest or value to the organization. The production engineering group is vitally interested in all these activities and should work in close cooperation with this division.

(*f*) *Public relations division.* Many organizations have established a public relations division through which technical and other papers and information of general interest are cleared before publication. Members of the organization should be encouraged to belong to technical and professional organizations, and to take active part in their meetings and other projects.

These public relations divisions are generally established in the belief that the better the public understands the general problems and efforts of their organization, both technical and otherwise, the more

the public will appreciate their products. Many organizations publish technical bulletins, treatises, and other technical reports, some of which are issued periodically, to present information and data of general interest and application which have been determined and formulated by members of their organization. Relations with engineering and trade organizations are often maintained through such divisions.

(*g*) *Research division.* These divisions are organized to meet the specific needs of organizations. They are most common in industries whose products originated in the laboratory. Other industries are beginning to discover that a systematic search for needed information can be more effective than cut-and-try methods and reliance upon chance. In some organizations this division conducts research of a high order in the general field of its interests where the commercial applications are by-products. This division may be the functional design authority or it may concentrate on engineering research and tests from which information is obtained for process and product development. Contact with cooperative research projects of trade associations and engineering societies should be maintained through this branch.

(*h*) *Manufacturing division.* This division is charged with the actual production of the product and is often headed by the general manager of the plants. Production engineering is an integral part of this division.

(*i*) *Purchasing division.* This division conducts all negotiations with outside suppliers, issues the purchase orders for all divisions of the organization, finds sources of supply, and is largely responsible for the development of the general purchasing policies.

Manufacturing Division

The work of the manufacturing division may be divided into two principal activities: production scheduling, operation, and control; and production engineering. Production scheduling and control is an important and extensive activity, and many texts are available which discuss it in detail. Production operation includes the activities of all the direct producing personnel and their supervisors. One of the most important problems of production operation is the factor of human relations among the factory personnel. This factor is equally important in all other divisions.

A summary of production engineering will be made by dividing these activities into three groups, namely, product engineering, process engineering, and plant engineering.

Product Engineering

Among the many engineering activities that apply directly to the product are the following:

(*a*) *Functional design.* The responsibility for the functional design may rest with the research division or with one of the design branches of the engineering department of the plant. Production engineering activities, in themselves, start from some accepted functional design.

(*b*) *Production design.* This is the starting activity of production engineering, and it is one that is never finished. It is distinctly a creative effort at the start, but becomes largely a matter of routine correction and changing to keep the design records up to date after the initial production is well under way. The making of manufacturing models provides the earliest check it is possible to have on the first production design and makes possible early performance tests. It thus aids in the better selection of materials, extent of tolerances actually needed, and surface-finish requirements.

(*c*) *Inspection planning.* Closely allied to the production design is the planning for inspection. Test specifications for materials, essential sizes and features to be inspected, and all performance tests should be planned in detail in advance. In many respects, this work is another item of production design. In some plants this work is done by a special group which may be a part of the quality control organization.

(*d*) *Gage design.* A large part of this work is the selection of standard gages and other testing equipment for use on the particular product. In addition, some special gages and other special testing equipment must be designed and built to serve a particular purpose. After production has started, it is often necessary to add additional inspection equipment to control some feature of the design which has unexpectedly disclosed a temperamental behavior.

(*e*) *Check performance of new product at initial assembly.* This may include service and endurance tests on the manufacturing models as well as the critical study of the performance of the first products assembled from the tool-made parts.

(*f*) *Investigate and correct faults* which have developed during the initial production. These investigations should be made in close cooperation with the process engineering and the regular production force. In many cases, questions arise about the interpretations of the information which has been given on drawings and in other specifications. Sometimes an explanation alone is sufficient to clear up the question; in other cases a clearer exposition must be substituted on the drawings or in the specifications to clear up the matter. Other problems relating

to burrs, allowances, tolerances, and quality of surface finish are often involved and must be solved.

(*g*) *Quality control.* This includes the work in the chemical and materials testing laboratories which check the quality of the raw materials, all other preventive inspection, the floor or process inspection, the finished-parts inspection, the routine testing of the completed product, and all necessary service and endurance tests on the product.

(*h*) *Correction of production design.* This includes the routine changes necessary to keep the records up to date because of correction of errors, changes in processes, and changes and improvements in the product. A change in material or process may require a considerable change in the detail design.

(*i*) *Standardization.* Although the standards division has general jurisdiction over all standardization projects and organizes the specific groups for this purpose, the product engineering staff must do its part and take the lead, technically at least, in the standardization of product design practices, elements of the product, and shop standard parts and elementary surfaces. This work should be done in cooperation with all other interests which are in any way affected by these standards. One of the important functions of the standards division is to make sure that all interested parties have some voice in the formulation of these standards.

(*j*) *Product development.* Some of this work may be done in the general research division. A large part of the refinement and improvement of the product that results from the continued experience with it, both in its manufacture and with its use, and from the analytical study of its many elements, as well as from the substitution of new materials, is a definite task for the product design group.

(*k*) *Investigation of product performance in service.* The results of such investigations can be made one of the most potent sources of improvement of the quality of the product that it is possible to find. The needed information is there, and all that is needed is someone to recognize, collect, and apply it.

Process Engineering

Process engineering includes all those activities that involve the selection, use, and improvement of the many processes which are employed in the production of the component parts of the product. Among them are the following:

(*a*) *Estimating.* This is the starting activity of process engineering, and requires the services of men who are familiar with the plant, its personnel, its processes, and its past performances, and who have a

full knowledge of the product itself. These men need the full cooperation of the product engineering staff and of the production group, as well as reliable statistics from the time and cost department, if they are to do their work most effectively. These estimates are the basis for the budgets which are set up for the initial production.

(*b*) *Operation lists.* The most effective processes available and their sequence in use for the production of each component part of the product must be selected and listed by the process engineers. This work also requires the close cooperation of the production organization and the product design group. Small changes in design will often make possible many economies in production, and the earlier these changes are made the greater will be the economies. The effectiveness of the production design to a large extent receives its first test here. It is sometimes possible to work out many details of the production design as the operation lists are being made.

(*c*) *Factory layout.* When a plant is arranged so that the machines for successive operations are located in the order of their use for the machining of specific component parts, a new factory layout must be made for each new part that is to be produced. In other plants occasions arise when a regrouping of the equipment will reduce trucking and handling of the product. Here also factory layouts must be made for the equipment affected by such changes.

(*d*) *Tool design.* The tool designs may be made in a tool design section in the plant or they may be made by an outside tool shop. In either case the process engineering group is responsible for their satisfactory performance in use and should exercise sufficient supervision over them to meet these responsibilities.

(*e*) *Initial production.* The process engineering group is responsible for the starting of the initial production of a new product, both for the time when this production is started and the effectiveness of the processes and tools used for the production. To meet this responsibility they must set up definite time schedules for the starting and finishing of the tool design, for every operation on every component part, and also for the making of the tools. This work must be constantly followed up and its progress must be checked against the time schedule. The process engineers must supervise the original set-up and the start of production on every operation, and be sure that the production force has adequate information about each operation to carry on effectively.

(*f*) *Investigation and correction of faults in initial production.* These investigations are made in cooperation with the product design group since the faults may be in the design of the product or in the

design, construction, or operation of the manufacturing equipment. In any event, the fault must be detected and corrected.

(*g*) *Standardization of tools, and productive equipment.* Although all standardization activities are cooperative efforts, the process engineering staff should take the lead in all projects involving the tools and the equipment. Close coöperation with the product engineering group is necessary here if the maximum benefits are to be obtained. In fact, the more effectively the standardization of the product is carried out, the greater are the possibilities of tool and equipment standardization. Outside tool and equipment manufacturers should also be consulted when this type of material is standardized.

(*h*) *Standardization of processes.* This work must be done in close cooperation with the production group and the product engineering group. A large part of this work may consist of the development of general operating instructions for the several different processes employed. As much as possible of this information should be a matter of definite record arranged for ready reference.

(*i*) *Constant study of production processes.* Although the processes may be standardized, the process engineer should study them continually both to become better acquainted with their possibilities and limitations and also to take more advantage of their possibilities and, where possible, to reduce their limitations. Here the full cooperation of the operating personnel is most essential.

(*j*) *Cost reduction and revisions of operation lists.* As noted before, it is always possible to do any job more cheaply and better if sufficient effort is exerted to this end. Continued study of the processes, analyses of suggestions, and the cooperation of the machine operators will make evident many possibilities for the reduction of costs. When changes are made in the processes used, or rearrangements are made of equipment or improvements in processes, the operation lists and other records should be revised accordingly.

(*k*) *Factory cost accounting.* The process engineering group should establish and maintain close contact with the factory cost-accounting group. For one thing, they should help to make the information sent there from the shop as accurate as possible. Again, they should have these accounts arranged and assembled to suit their needs, and must make these needs clear to the accounting group. These efforts will give each group a better understanding of the other group's problems. This is one of the essentials to effective cooperation. In addition, statistics from the cost-accounting group form the basis of much of the estimating.

(*l*) *Time and motion studies.* This is a tool of the process engineer

which may be used for many purposes. Among others, it makes possible an accurate check on original estimates, it collects further data for the use of the estimators, and it is often used at the start of a cost reduction project.

(*m*) *Operator and equipment studies.* It is essential to know the characteristics and range of skill of the operator who is needed to perform specific operations, particularly the critical ones. Information gained from such studies forms a good basis on which to make plans for further training courses. The personal contacts made here can also help in the selection of individuals for advanced training. This work must be done in close cooperation with the production group.

(*n*) *Routine set-up.* This task is the responsibility of the production group but the process engineer should cooperate here whether he is definitely attached to the production group or not. Errors and omissions in the operating instructions may become evident when setting up for a product which has not been made for some time, and these shortcomings should be corrected. This is definitely a responsibility of the process engineer.

(*o*) *Process development.* Any specific process development project may be started in the general research division, but the process engineering group should carry it through the stages between the laboratory process and the standard production process. Some process engineers may be transferred temporarily from the production group to the general research division to assist in such a process development, and stay with it until it has become a standard shop process. All new processes should be thoroughly tested before they are installed in the routine production line.

Plant Engineering

Plant engineering includes the installation, maintenance, and operation of all general plant services and facilities which are not assigned to specific production processes or operations. When new buildings or additions to existing buildings are required, this work should be done under the supervision of the plant engineering group. This work also includes the care and maintenance of the grounds around the buildings. Among the many tasks assigned to the plant engineering group are the following:

(*a*) *Plant maintenance.* This includes all maintenance of the buildings and grounds, elevators, fire prevention equipment, watchmen and plant guards, etc. This work may require a considerable force of painters, carpenters, plumbers, electricians, janitors, and others.

(*b*) *Basic factory planning.* The basic factory planning is the set-

ting-up of standards for the location and installation of many of the general plant facilities. Such work should be done in close cooperation with the process engineering group. Although much can be done in this field, only a few plants have appeared to give it serious consideration, and practically nothing has been done along these lines by trade associations or by engineering societies.

(*c*) *Safety and accident prevention.* In many plants, a safety engineer is attached to the plant engineering group who is charged with the duty of designing and installing all safety equipment such as guards around dangerous equipment, and of eliminating as many hazards as possible. It is his responsibility to see that all legal and other accepted safety codes are met. First-aid stations and supplies may be under his supervision or they may be operated as an independent unit.

(*d*) *Power and light.* This group installs and maintains all equipment needed to provide power and light for the plant. When a plant generates its own power, the plant engineering group operates this power plant. When electric power is purchased, this group connects and gives maintenance service to the electric motors which drive the productive equipment. Periodic power surveys are advisable if the electric current is purchased, to insure that the purchased current is used most effectively.

(*e*) *Heating and ventilating.* The installation, operation, and maintenance of the heating and ventilating equipment used in the plant, as well as the design and operation of any exhaust systems that may be required, are the responsibility of the plant engineering group.

(*f*) *Sanitation.* The plant engineering group must install and operate all washrooms, locker-rooms, and all other general facilities required for the general use of the personnel and sanitation of the plant.

(*g*) *Installation of equipment.* This group is responsible for the moving and installation of all machinery and other equipment required in the plant. The specific location of each piece of productive equipment is given by the plant layout. This is made by the process engineering group.

(*h*) *Auxiliary facilities.* As far as possible, all auxiliary facilities such as compressed air, steam, hot-water, and electric-power lines should be installed according to some basic factory plan so that other connections can be conveniently made when needed. The installation and maintenance of these facilities is a responsibility of the plant engineering group.

(*i*) *Materials handling.* The installation and maintenance of materials-handling equipment is another responsibility of the plant engineering group. When parts are moved by trucks or traveling cranes,

the operation of the equipment belongs to this group. The handling, storing, and issue of raw materials may be included here.

(*j*) *Salvage of chips and other scrap material.* The collection, storage, baling and disposal of chips and other scrap material is another general shop service that may be assigned to the plant engineering group. When the rate of production is high, the collection and disposal of these chips may become a serious problem.

(*k*) *Receiving and shipping.* The trucking, handling, and boxing and crating of materials and products, together with the operation of the receiving and shipping department, is still another general shop service activity that can logically be assigned to the plant engineering section. The receiving and shipping department must work in close cooperation with the purchasing, production, and sales groups.

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